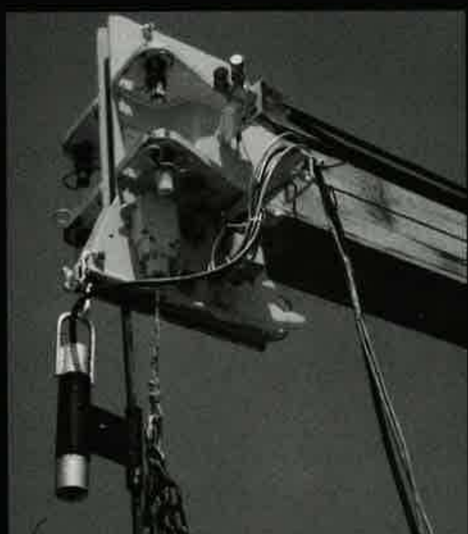
JANUARY–FEBRUARY 1995
NUMBER 176

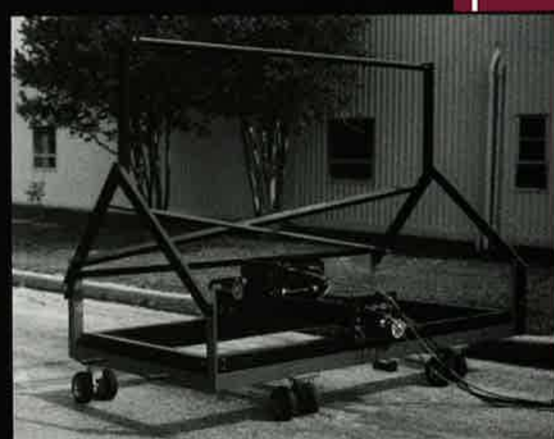
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

TR NEWS

SPECIAL ISSUE

AUTOMATION AND ROBOTICS IN HIGHWAY DESIGN, CONSTRUCTION, AND MAINTENANCE





The **Transportation Research Board** is a unit of the National Research Council, which serves as an independent advisor to the federal government on scientific and technical issues of national importance. The Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear on national problems through its volunteer advisory committees.

The mission of the Transportation Research Board is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 300 committees, task forces, and panels composed of more than 3,900 volunteer members, including administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

TR News features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also featured, along with profiles of transportation professionals, meeting announcements, reviews of new publications, and news of Transportation Research Board activities.

JANUARY–FEBRUARY 1995 NUMBER 176

TR NEWS

TR News (ISSN 0738-6826) is issued bimonthly by the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America.

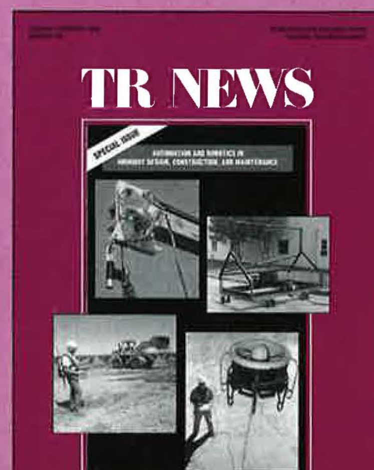
Editorial Correspondence: By mail to the Reports and Editorial Services Office at the address above, or telephone (202) 334-2972, fax (202) 334-2519.

Subscriptions: Rates for North America: 1 year $47.00 ($58.00 overseas); single issue $8.50 ($11.50 overseas). Inquiries or communications concerning new subscriptions, subscription problems, or single-copy sales should be addressed to the Business Office at the address above, or telephone (202) 334-3214, fax (202) 334-2519. Second-class postage paid at Washington, D.C.

Postmaster: Send changes of address to *TR News*, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

12

28



COVER: This special issue of *TR News* focuses on automation and robotics, which are increasingly being used in highway design, construction, and maintenance. The benefits resulting from this technological revolution include added safety in the workplace, more timely completion of work, improvement in quality, and utilization of the superhuman capabilities of automated systems. Other pockets of automation can be observed in computer-aided design and intelligent transportation system applications. [*photographs* (clockwise, top left): *North Carolina Department of Transportation; Dailey/University of Texas, Austin;* (next two) *Caltrans.*]

AUTOMATION AND ROBOTICS IN HIGHWAY DESIGN, CONSTRUCTION, AND MAINTENANCE

AUTOMATION AND ROBOTICS Past, Present, and Future

CHRIS HENDRICKSON

Although highway construction and maintenance have become highly mechanized, only specialized applications of automation and robotics have been implemented. The underlying technology for automated fieldwork, however, continues to improve and to become less expensive. Computer hardware alone has been increasing in capability at a rate of 30 percent per year, and distributed computing is a key technology for field automation. New sensors and control systems are also appearing. This technological revolution will lead to significant opportunities for roadway construction and maintenance.

This special issue of TR News *focuses on automation and robotics in design, construction, and maintenance. Presented in the following articles are some basic definitions of robotics and automation, answers to often-asked questions, and a review of the current state and prospects of new automated systems.*

Appreciation is expressed to TRB staff members Frederick D. Hejl, Engineer of Materials and Construction, and G. P. Jayaprakash, Engineer of Soils, Geology, and Foundations, for overseeing the preparation of this issue on automation and robotics.

Chris Hendrickson is Associate Dean and Professor, Department of Civil and Environmental Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania.

What is automated and robotic equipment?

In contrast to the image developed in popular movies, robotic equipment is not necessarily humanoid, with walking legs and mechanical arms. The many degrees-of-freedom arms seen on industrial robots used for welding or paint spraying have only limited roles to play in field construction or maintenance. A more important consideration is the type of control and sensing used.

Construction and maintenance equipment can be divided broadly into four categories of control:

- *Mechanized equipment* is familiar in most field applications for tasks such as grading, excavation, and maintenance.
- *Numerically controlled equipment* is in common use for slipforming and paving applications. NC machines use limited sensors only for tasks such as following a straight line or regulating the flow of materials.
- *Remotely controlled equipment* has physically separate operators that typically must rely on sensor information to operate the equipment effectively.
- *Semiautonomous and autonomous equipment* relies on environmental sensors and computer algorithms to make decisions about equipment operation and movement. For example, semiautonomous grading equipment is driven by a human operator but the blade height and pitch may be controlled automatically. An autonomous dump truck could drive itself to and from loading and dumping areas.

Although there are always exceptions and qualifications, remotely controlled and semiautonomous and autonomous types of equipment are commonly considered automated or robotic equipment.

What can automated and robotic equipment contribute?

Improved safety is the most obvious advantage of automated equipment. Roadway maintenance in active traffic areas is inherently hazardous, even with special barriers, warnings, and protective procedures. Bridge and pier inspection carries the risk of injuries and avoiding a single fatality or major injury could justify the use of new equipment. Health hazards are associated with some roadway construction and maintenance tasks, such as removing lead-based paint, and the use of robots could keep humans out of range of such danger.

The opportunity to take advantage of superhuman capabilities is another benefit offered by automation. Small robots can move through drainpipes for inspection and repair. Sensors can pinpoint reinforcing steel embedded in concrete. Precise control of actions such as crack cleaning could lead to improved quality. With automated machinery, work could continue for long periods without the complication of complaints about night shifts or overtime.

What are possible applications for this equipment?

The ideal application for automated and robotic equipment would (*a*) include high costs to justify new equipment investments; (*b*) have high volume to spread development and investment costs over numerous applications; (*c*) be performed within a hazardous environment; (*d*) involve simple, repetitive tasks; and (*e*) have a stable and predictable environment to avoid the necessity for sophisticated monitoring and control. Few roadway construction and maintenance tasks include all these characteristics, especially a stable and predictable environment, but many have some of these ideal elements. Numerous possible applications are discussed in the following articles.

How do automation and robotics relate to computer-aided design (CAD) and intelligent transportation systems?

Transportation systems have pockets of automation and of computer-based representations. For example, CAD drawings are being prepared for new roadways, but the actual construction is still based on paper printouts from the CAD system. In addition, many trucking firms track their vehicles automatically throughout the country using global positioning systems and other technologies. Toll collection and vehicle identification are also being automated, but these pockets are usually isolated from each other and from nonautomated processes. Some significant benefits are likely to result when these pockets of automation are extended and interconnected. For example, construction progress can be monitored and quality assured with field sensors and real-time information feedback. Accurate electronic models of facilities in place can be used for maintenance automation and for intelligent roadway operations.

What is slowing the introduction of automation and robotic equipment?

Roadway construction and maintenance present some extreme equipment demands. The environment is rugged, large forces are required, equipment longevity is imperative, the underlying tasks are diverse, and stringent cost restrictions are the rule. Most robot implementations to date have been conducted in controlled environments such as manufacturing plants, so field applications require some additional development. Even in industrial plants, successful automation has required the redesign and reengineering of manufacturing tasks as well as extensive experimentation and training for personnel. Both technical challenges and organizational barriers to change must therefore be overcome before use of new equipment can become widespread.

In contrast to the image developed in popular movies, robotic equipment is not necessarily humanoid, with walking legs and mechanical arms.

Will automation and robotic equipment be introduced in the near future?

In many cases automation has already been introduced and is moving toward more capability and machine control. Examples of existing automation are flow controls for pavers and height controls on grading equipment. Engine maintenance is being automated with extensive computer monitoring and diagnostic aids. Sophisticated guidance and control technology is used in tunneling technology. In addition to this evolutionary improvement, the introduction of new, specialized equipment with robotic characteristics is likely for applications such as bridge inspection or painting. Although complete replacement of construction and maintenance personnel will not take place in the near future, workers will increasingly become equipment managers, responsible for monitoring and managing the work of automated systems.

What are the implications of these changes for the future work force?

As is the case in many sectors of the economy, these technological changes will put a premium on broad-based technical skills for both workers and engineers. Some basic knowledge of electrical circuits and computers will be helpful for field workers. For engineers, interdisciplinary problem-solving skills will be needed, and a civil engineering education should include exposure to electromechanical devices and the professional uses of computer systems. In future years a master of science degree may become the normal requirement for work as a professional engineer.

The efforts of Chris Hendrickson, past Chairman of TRB's Committee on Applications of Emerging Technology, are acknowledged in planning this issue of TR News *focusing on automation and robotics in highway design, construction, and maintenance, in acquiring the articles, and in overseeing the review process.*

—Nancy Ackerman
Editor, *TR News*

Evolving Automation in the Asphalt Paving Industry

THOMAS D. WHITE

The evolvement of processes and equipment has made the asphalt industry a fertile area for automation in construction. The asphalt pavement construction industry, spurred by competition and the desire to improve quality, has responded by adopting automation concepts and contributing to the development of rugged, dependable automation components. Although other areas of construction have struggled to fund automation costs, the paving industry has developed incentives and quality control processes that encourage investment.

Asphalt Plants

Over the years asphalt plant designs have changed significantly. These changes have been driven by a desire to improve working conditions, lessen environmental impact, increase production, respond to changes in pavement material technology, and reduce initial and maintenance costs of plants.

The traditional picture of an asphalt plant belching dust and smoke, with the plant operator standing on a platform in the midst of it all, pulling levers to proportion aggregate and asphalt, is in contrast to modern automated asphalt plants (Figure 1). Transition from that historical vision has been incremental. The plant calibration process has changed. Early methods involved weighing aggregate and binder samples with platform scales. Today's plant can be calibrated much faster because of aggregate belt scales and binder flow rate sensors that are integrated into the plant controls. With such facility the proportions of one or more mixtures can be set and stored, and later produced on demand.

A significant change has taken place in mixture temperature control. In early plants mixture temperature was determined with a thermometer and any necessary modifications were made by manually adjusting the burner. Subsequently a temperature probe was installed to obtain a continuous, remote readout or a permanent graph of mixture temperature versus time at the plant control panel. Recent refinements have resulted in the automation of temperature control.

Automation has progressively improved working conditions in asphalt plants, particularly for the plant operator. Lever pulls have been replaced by standoff pulls with cables from a control room. Further development has allowed an increasing number of plant processes to be controlled electronically. The modern asphalt plant control room is airtight, air conditioned, and equipped with a control panel comparable to any automated manufacturing process.

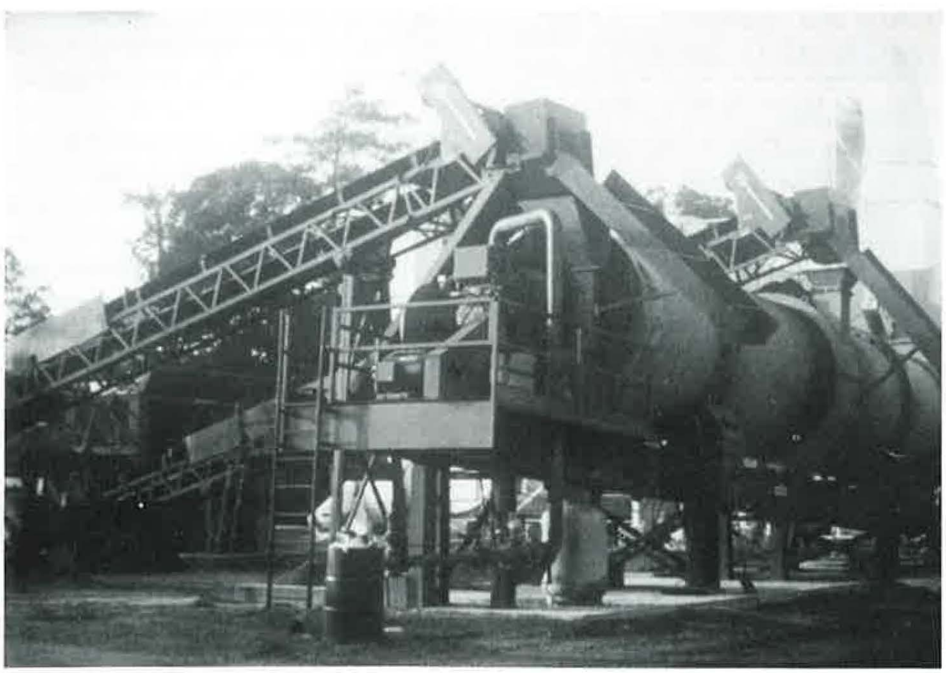


FIGURE 1 Drum mix plant.

Thomas D. White is Professor of Civil Engineering, Purdue University, West Lafayette, Indiana.

New features and designs have been developed for asphalt plants. The most notable is the baghouse, which collects dust from aggregate drying and other points of processing and feeds it back into the mixture, thereby minimizing the environmental impact. Effective baghouse operation depends on automatic controls. Asphalt plants have been modified or built to allow incorporation of more components into asphalt mixtures. For instance drum mix plants feature a port for the mid-drum addition of a mixture component such as recycled asphalt pavement. Multiple in-drum pipes provide injection points for asphalt additives or modifiers. These additional components are automatically proportioned to achieve the desired properties and to maintain mixture quality.

FIGURE 2 Twin windrow pickup.

Material Delivery

Asphalt pavement quality depends on uniformity of the material streams during the paving operation (*1*), including delivery of the asphalt mixture to the paver. Ancillary equipment is being developed to enhance the uniform flow of the paving mixture. The asphalt mixture can be delivered to a windrow on the pavement in front of the paver. Subsequently a windrow pickup device loads the mixture into the paver. As a result, surge capacity is provided ahead of the paver, which allows the paver to run at a constant speed. This process minimizes variation in the material passing through the paver and the head in front of the screed.

By integrating the pickup device into the paver, larger surge capacities are possible (18 tons on rubber-tired machines and 25 tons on track machines). These larger capacities can even out variations in the cross section of the windrow and allow the paver to operate at a constant rate of production. Augers on the outside of the pickup device allow for pickup of twin windrows or for windrows placed inaccurately (Figure 2).

An integrated paver with a truck dump allows trucks to be unloaded into the machine at a very high rate [(1100–1400 metric tons per hour) (1,200–1,500 tons per hour)]. With a 23-metric ton (25-ton) surge capacity, trucks can be quickly unloaded without running the paver at high rates of speed, resulting in continuous operation.

A material transfer vehicle can unload a truck at the rate of 1100 metric tph (1,200 tph) and convey the mix into its 32-metric ton (35-ton) storage hopper. Use of a material transfer vehicle has contributed to smoother pavements, reduced segregation, and uniform high density.

Paving Machines

Paving machines are used to build smooth pavements and were designed to mechanically provide this function, thereby introducing an early degree of automation in the asphalt paving field. Many of the settings on the early pavers were made manually, but through the years these were also automated. Automation was incorporated to improve productivity while maintaining or improving pavement quality.

The basic automatic feature of an asphalt paving machine is the floating screed. This feature was part of the early paving machines (Figure 3). As the paver moves forward, the screed, on the basis of its weight, support from the paving material, material resistance, and pulling force, seeks an equilibrium condition that provides an automatic smoothing function as long as the screed is moving. Modern paving machines (Figure 4) include the original floating screed plus automation to maintain longitudinal and transverse grades. Options for longitudinal grade control include individual sensors, extended multipoint reference sensors, single stringlines, and dual stringlines. A multipoint reference beam and a single stringline reference system are shown in Figures 4 and 5, respectively. More recently, broadcast lasers have been considered.

FIGURE 3 Early paving machine.

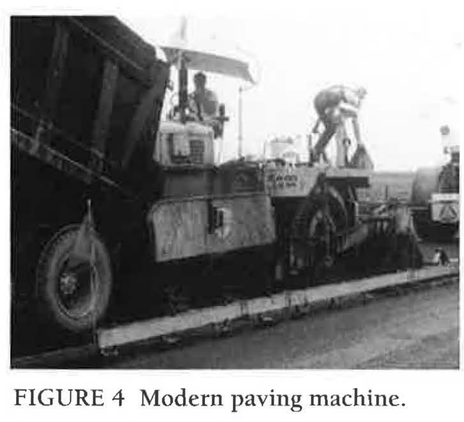


FIGURE 4 Modern paving machine.

Potential Technology

The dispersed nature of pavement construction lends itself to applications of global positioning systems (GPSs). For example, asphalt plant production and paving operations depend on transportation efficiency. Transmitters in each truck and on the paver and other equipment could provide real-time management of construction processes and operations. With the sensor technology available, material characteristics, such as asphalt mixture temperature, and equipment functions, such as fuel consumption, could be monitored. In the former, temperature could be immediately adjusted at the asphalt plant. In the latter, a fuel truck could be dispatched and the best route planned using GPS and an associated geographic information system. Simple two-way radios or telephones could be replaced with computer terminals.

Additional automation features may be possible for asphalt plants. As sensor technology and analysis continues to develop, points in the mixture production process can be monitored for gradation, asphalt content, and uniformity. This may be possible with image analysis or infrared monitoring. The plant can also become self-monitoring by using image analysis, infrared, and sonic techniques.

Further automation of the paving process is being explored. Nakamura et al. (2) reported on a three-dimensional positioning, automatically controlled asphalt paver, which includes a closed-loop system of guidance and control. The three-dimensional plan is transmitted to the paver, where sensors provide data for position and attitude of the paving machine. Error adjustments are calculated and implemented.

Control during paving may be enhanced with on-board sensors (sonic or laser) that could scan the pavement surface. Micro-screed adjustments would be possible for the profile and cross section. The problem of rutted pavements could be addressed with a segmented screed that would leave additional mixture over a rutted area. The mixture would contribute to higher density and reduced compaction by traffic.

Summary

A barrier to construction automation that is frequently discussed is cost recovery. In paving, continued enhancements to automation contribute to smoother pavements. Longer performance life and lower maintenance costs result. Consequently, from a life-cycle analysis, highway agencies can afford to invest additional money in building smoother pavements.

References

1. Brock, J. D. *Pavement Smoothness.* Technical Bulletin T-123, ASTEC Industries, Chattanooga, Tenn., June 1992.
2. Nakamura, T., T. Kirlyama, M. Fukuda, T. Maeda, M. Fukukawa, S. Nagasaki, Y. Fujiwara, K. Sugano, F. Goto, T. Namekawa, K. Denda, and Y. Ageishi. Development of Three-Dimensional Positioning Automatic Control Asphalt Paver. *Automation and Robotics in Construction,* XI, Elsevier B.V., The Netherlands, 1994, pp. 47–54.

FIGURE 5 Stringline reference.

AUTOMATION AND ROBOTICS RESEARCH
THE FEDERAL HIGHWAY ADMINISTRATION

DAH-CHENG WOO

In April 1992 the Federal Highway Administration formally established the Office of Advanced Research for the application of the latest technical advances to highway transportation. One of the six major areas of research is named robots/-automation/man-machines. Research on remote controlled equipment began with the Strategic Highway Research Program in the form of a pothole repairing machine and an automatic pavement crack sealing machine. The establishment of the Office of Advanced Research acknowledges the potential impact of this area of research on the highway industry.

Program

The current program, which deals with construction, maintenance, and operation, has three major goals: to enhance safety, improve quality, and increase the productivity of highway transportation. FHWA's special projects on intelligent transportation systems are not included.

The program consists of research for innovative ideas, feasibility studies, and the development of final practical products for use by highway practitioners. To take advantage of as many resources as possible, FHWA not only sponsors robotics research studies, but also encourages state participation through the State Planning and Research (SP&R) program and other joint application studies.

Accomplishments

Through an interagency agreement, the National Institute of Standards and Technology conducted an in-depth study of the application of robotics to highway transportation. A panel of robotics experts of many disciplines was assembled for the study, which included workshops, site visits to highway construction projects, and numerous discussions with state highway personnel, contractors, and equipment manufacturers. After the final analysis of cost-benefits, four areas of research with significant potential value to the highway industry were identified: site integration, automated pavement inspection and crack sealing, automated bridge inspection and maintenance, and automated bridge deck construction. The study set the tone for FHWA's robots/automation/man-machine research for the next five years.

To stimulate innovative ideas, FHWA awarded two research grants in this area in 1993. After a year of intensive work and the support of the North Carolina Department of Transportation, North Carolina State University, under the leadership of Leonhard E. Bernold, produced and field tested an initial prototype of robotic bridge paint removal equipment (see the article by Luces et al. elsewhere in this issue). This prototype shows great potential for the development of equipment for safe and accurate bridge paint removal. It can also be modified for bridge inspection and painting. The University of Arkansas at Little Rock, under the guidance of J. Douglas Wilson, successfully researched and constructed a second-generation imager, optimized for aggregate analysis. This equipment has been tested with known samples.

Current Research

Ongoing research includes a study at the University of Texas at Austin, jointly sponsored by FHWA and the National Science Foundation, on a large manipulator for use by the highway industry. Another pooled-fund study conducted by the California Department of Transportation involves the development of an aerial bridge inspection device for safe initial bridge inspection (see article by West et al. in this issue).

FHWA has initiated a long-range new research project on site integration. It is believed that by integrating design, planning, scheduling, and real-time control of operations, computer technology can be used to assist human operators and supervisors at all levels to apply their knowledge and skills in more efficient ways. Computer use can help a project proceed smoothly with minimum interruption and delay and can greatly increase the safety of workers, quality of work, and project productivity. Thus the time needed to complete a construction project can be shortened and the total cost considerably reduced.

In 1994 North Carolina State University was awarded a grant to conduct a study on trench excavation and pipe-laying. Researchers will investigate the technical feasibility and effectiveness of a laser-based spatial position control under real field conditions and innovative technology for the detection of buried metal obstacles.

A minor development study of a semi-automatic pavement crack sealing machine is being sponsored jointly by the FHWA's Office of Technology Application, the Texas Department of Transportation, and an equipment manufacturer. This research will advance technology initiated in a SHRP study (see article by Haas and Dailey in this issue).

Future Plans

Future research will focus on increasing the safety of highway workers and users and providing better quality highways. It will cover more innovative ways of continuously monitoring highway pavement performance and earlier stress detection; improved methods for safety zone traffic control; and sound, continuous bridge inspection, which includes the underwater inspection of abutment and pier scour. Research will be continued on the development of environmentally sound and continuous operation for bridge painting and bridge paint removal. These studies are part of FHWA's continuing program to seek innovative ideas for improving highway transportation.

For additional information on FHWA's automation and robotics program contact Dr. Dah-Cheng Woo, Hydraulic Research Engineer, Office of Advanced Research, Turner-Fairbank Highway Research Center, Federal Highway Administration, 6300 Georgetown Pike, McLean, Virginia 22101-2296.

TEXAS
Automation Opportunities in Highway Construction and Maintenance

CARL HAAS and CHARLENE DAILEY

Automated road maintenance can directly improve safety, pavement quality, working environment, and productivity. Indirect savings can be achieved by reducing the disruption to normal road use caused by work crews. Because of the potential benefits offered by this technology, the conceptual feasibility of automating the major maintenance activities of the Texas Department of Transportation has been evaluated (*1*). This has involved a detailed analysis of TxDOT's maintenance budget, individual surveys of TxDOT personnel, and a broad-based technical investigation. As a result of the evaluation, automated crack sealing was identified as a high-need area and a review of the technical feasibility of implementing this procedure was undertaken. A discussion of automated crack-sealing equipment, developed on the basis of a graphically controlled, *XY*-table design, is presented here.

Evaluation of Technologies

Automation technologies exist along an evolutionary continuum from concept to commercial prototype. At the University of Texas (UT) at Austin, engineers have developed an automated road maintenance evaluation model through which maintenance activities or systems designed to automate those activities can be evaluated from quantitative and qualitative perspectives (*1*). Three phases of evaluation are defined to thoroughly address available opportunities: (*a*) needs assessment and conceptual feasibility, (*b*) technological feasibility, and (*c*) field testing. In each phase the potential benefits of automation are evaluated from economic and qualitative perspectives.

In the first phase, maintenance activities that are conceptually feasible for automation are identified and ranked in terms of the opportunities they present for automation. In the second phase, the anticipated feasibility of one or more selected prototype systems is evaluated. In the third phase, field trials for selected systems are recommended for compilation of performance data, bench marking for comparison, and training.

A needs assessment study for Texas focused on road maintenance activities. Twenty-five activities making up 75 percent of the state's maintenance budget were examined in detail and a cost-concern matrix was formed on the basis of the results of this study. The concern rating formula for deriving the *Y*-axis value incorporates productivity, quality, safety, and sociopolitical, technological feasibility, ergonomic, and user cost factors. TxDOT engineers consider safety the most important factor for indicating the need for automation. The X-axis of the cost-concern matrix is based on yearly maintenance expenditures, and this scale can vary from one public agency to another. Distance from the origin is a crude but effective measure of automation need or opportunity.

Leveling or overlays consume a significant portion of the maintenance budget. Related concerns about safety, quality, and user delay costs resulting from overlay operations indicate that there is a need to improve the technology of leveling and overlays. Similar concerns exist for milling and paving operations, and equipment manufacturers have responded by developing cable- and laser-guided automated level control systems. Recently multimillion dollar consortia have been formed in Japan and the United States to develop and then apply real-time three-dimensional positioning systems to the control of earth-moving and paving equipment. These procedures will eliminate the need for grade stakes and most related surveying work and will facilitate grading and laydown of complex curves directly from computer models.

Other identified needs are already being addressed by the Federal Highway Administration and state departments of transportation(2). Prototype automated equipment for line painting, marker placement, pothole filling, garbage pickup, and other procedures already exist. In Texas crack sealing has been considered an area of particular concern because of safety, productivity, and road user delays. A feasible approach for its automation has been identified and demonstrated.

Automated Pavement Crack Sealing

Need

Approximately $200 million is spent annually on crack sealing in North America. It is a widespread, dangerous, labor-

Carl Haas is Assistant Professor and Charlene Dailey is Research Engineer, Department of Civil Engineering, University of Texas at Austin.

intensive, and costly operation, and it imposes significant costs on road users because of the disruption of traffic. Removing workers from the process reduces their exposure to traffic and lowers operating costs. Automation could also result in increased process speed and decreased road user costs. Approximately 25 percent of crack-sealing operations nationwide is privately contracted. In Texas the figure is about 50 percent of the approximately $7 million spent annually. Labor costs average about 60 percent of total crack- sealing costs. These numbers give a broad indication of the potential impact of automated crack sealing.

In Texas, according to the most recent economic analysis, statewide implementation of automated crack-sealing methods would produce estimated savings of $2.4 million for TxDOT (at 4 percent minimum attractive rate of return) and $2.6 million for private contractors (at 20 percent minimum attractive rate of return) during a 6-year planning horizon. The user-cost savings based on an approximately 25 percent efficiency improvement are estimated using the QUEWZ-E model to be $11 million for the 5150 kilometers (3,200 miles) of Interstate highways in Texas. Total user-cost savings would be much higher because the savings on urban freeways and streets, farm-to-market roads, and secondary roads are not included. From a national perspective during a 30-year planning period, the net current worth of automated crack sealing could be in the hundreds of millions of dollars.

Development

Current crack-sealing methods (Figure 1) require a crew of five to nine laborers to perform a combination of the following tasks. Depending on the state, they would (*a*) rout the crack, (*b*) blow it clean with compressed and sometimes heated air, (*c*) fill it with sealant, (*d*) squeegee it clean, and (*e*) cover it with sand or other material. Blowing and sealing are the most common operations.

Several prototype automated crack-sealing devices have been built. Originally the automated crack-sealing system was envisaged as an equipment train that included an equipment trailer, a manipulator, and a large van containing computer and power equipment (Figure 2). Blowing and sealing operations were to be automated. Manipulator options were considered, and an *XY*-table configuration was selected because of its ease of control and robust physical characteristics. Multisensor machine vision was proposed for automated crack mapping with system autonomy as the end goal. A project to implement this design was started at Carnegie-Mellon University (CMU) in 1989, and a working system was demonstrated a year later (*3*).

On the basis of the success of the first laboratory prototype, development of a field prototype was funded with approximately $100,000 from the Strategic Highway Research Program IDEA (Innovations Deserving Exploratory Analysis) program and $20,000 from the California Department of Transportation. Design objectives were to consolidate control and data processing on a single Intel 386 PC and to demonstrate operation of the system, still connected by an umbilical cord to the laboratory, on random unrouted cracks in a parking lot. A more robust *XY* manipulator was fabricated (Figure 3), and a revised control loop was implemented. Although demonstrated successfully a year after beginning the second phase, the system was retarded by slow range scanning speed.

Since that time a number of studies have shed additional light on the problem. These studies include reviews of methods, practices, and productivity of crack sealing in Texas; sensor fusion methods; and the maintenance automation needs already described. The SHRP sealant materials study and the FHWA-sponsored highway robotics seminars in 1992 and 1993 are also relevant.

Key design objectives for automated crack sealing have been distilled on the basis of the knowledge and experience gained from the preceding development efforts. The goals are (*a*) flexibility to handle different practices, (*b*) operation at manual crew speed or faster, and (*c*) a unit cost of less than $100,000. To meet these objectives, a graphically controlled system using an *XY*-table manipulator has been designed. FHWA, TxDOT, a crack-sealing equipment manufacturer, and UT at Austin are providing more than $300,000 in support of a two-phased implementation of this modified design. Commercial sealing equipment is being integrated with modified hardware and software from the CMU/UT prototype. Field trials for the first phase will be conducted in June 1995. It is estimated that

MALEK/UNIVERSITY OF TEXAS, AUSTIN

FIGURE 1 Conventional crack-sealing methods.

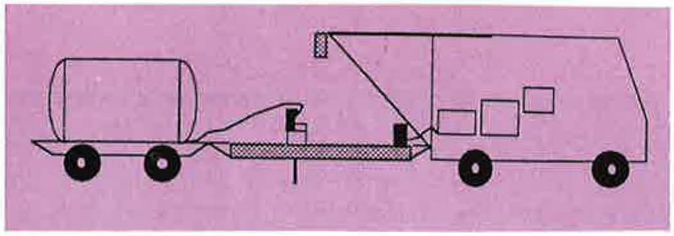


FIGURE 2 Conceptual prototype of the automated pavement crack sealer.

the system could be sold for considerably less than $100,000.

The new design combines computer-assisted manual control with the previously developed machine vision software and *XY*-manipulator hardware to implement a simple, high-speed automated system. The driver of the lead truck first moves the equipment train and stops over a cracked section. Presented with a high-resolution video image of the work area, the driver indicates the crack network graphically by using a light pen. Although some error is expected because of limited hand-eye coordination, machine vision software is used to center the manually drawn lines along the crack spines. The *XY* manipulator is used much like a plotter to draw the blowing and sealing tools over the cracks, and the driver moves on. Computer-assisted manual control circumvents problems previously associated with autonomous crack mapping, which required time-consuming range scans to differentiate cracks identified with machine vision from various road markings.

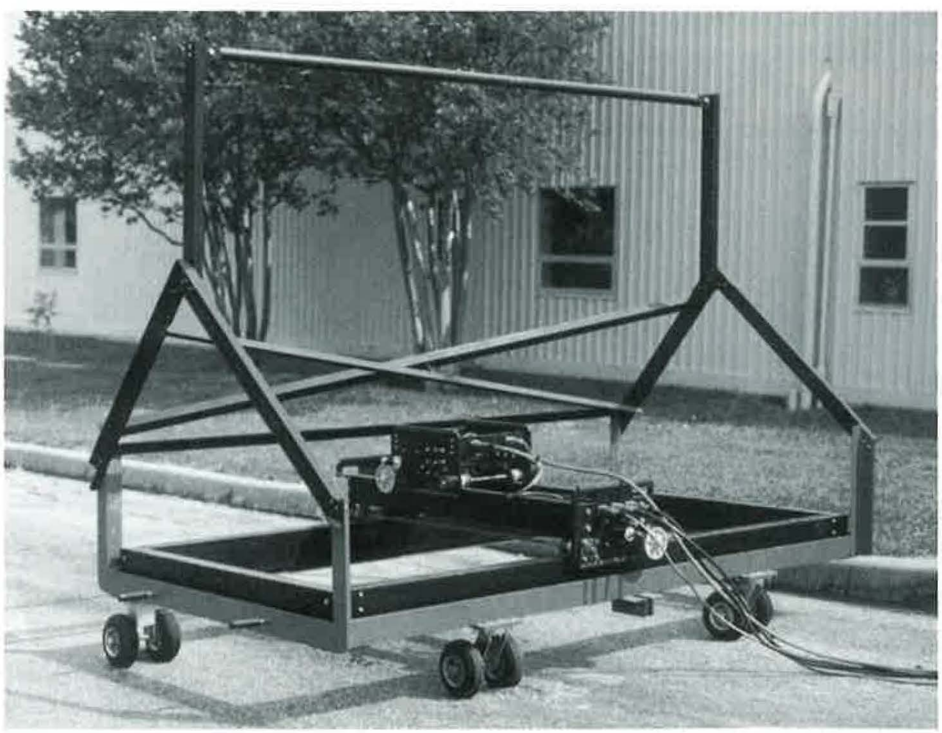
Significant technical challenges addressed in the first phase of this implementation effort include (*a*) optimization of the ergonomics, (*b*) calibration and alignment, and (*c*) dynamic control of the manipulator for high-speed movement. Technology and lessons learned from the first phase will be used in the second phase of the effort to develop a commercial prototype using off-the-shelf hardware and hardened components. Field trials and demonstrations of the commercial prototype are expected in July and August 1996.

Economic Feasibility

After all this effort, will anyone actually buy an automated pavement crack and joint sealing system? Only 16 percent of private contractors who perform crack sealing earn annual revenues of more than $1 million, and their revenues cannot be solely attributed to crack sealing. Only a small percent will be able to invest in automated systems initially; however, the associated benefits should increase their competitive advantage. These contractors will likely go on to dominate the market.

Government agencies may also purchase automated crack sealers. Twenty-five highway districts in Texas are authorized to purchase such equipment. Local municipalities and contractors augment the potential market. Impediments do exist, however. These include the practice of performing crack sealing with crews otherwise left idle when larger construction projects are threatened by inclement weather, or simple reluctance expressed by focus groups to spend large amounts of money because of perceived risk. Agencies are, however, becoming increasingly sensitive to safety and to the road user costs imposed by lane closures. Automated crack sealing will address these concerns and reduce operating costs.

In other areas of automated maintenance and construction, evolutionary developments in conventional overlay, patching, grading, and paving machines will continue to emerge. In the next decade automated, three-dimensional positioning systems based on global positioning systems and laser technologies will make a revolutionary impact, and innovative systems such as the crack sealer, pothole patcher, and line-painting machines will become commercially viable.



DAILEY/UNIVERSITY OF TEXAS, AUSTIN

FIGURE 3 First field prototype crack-sealing system.

Acknowledgments

The authors wish to thank the agencies mentioned in the article for their support of the work described. Dozens of individuals have also contributed significantly to the development of the crack sealer, and the authors wish to thank them for their past and continuing involvement.

References

1. Osmani, A. *A Model for Evaluating Automation in Road Maintenance.* M.Sc.

thesis, Department of Civil Engineering, University of Texas at Austin, 1994.

2. *Application of Robotics and Automation to Highway Construction, Maintenance, and Operations—2nd Workshop.* FHWA-RD-94-051, U.S. Department of Transportation, Federal Highway Administration, Turner-Fairbank Highway Research Center, 1993.
3. Haas, C., C. Hendrickson, S. McNeil, and D. Bullock. A Field Prototype of a Robotic Pavement Crack-Sealing System. In *Proc., 9th International Symposium on Automation and Robotics in Construction,* Tokyo, Japan, June 1992, pp. 313–322.

AUTOMATION IN DESIGN
NCHRP Activities

The move by the transportation industry toward increased automation of design activities has resulted in the need for research to better develop and incorporate automated processes. A number of projects are being conducted under the National Cooperative Highway Research Program to address these needs and will provide tools for faster and less labor-intensive performance of various design processes. The following are examples of NCHRP projects covering several functional areas that will lead to the creation of new tools for automated design.

Bridges and Structures

NCHRP Project 12-26/2: Distribution of Wheel Loads on Highway Bridges—Analysis Software

The anticipated distribution of wheel loads on a bridge has a significant effect on its design. Bridge engineers need fast, efficient tools to assist them with distribution analyses during the design process. NCHRP Project 12-26/2 is providing software to help in this work.

In the precursor to this project numerous variables affecting the distribution of wheel loads were considered, and recommended design provisions applicable to service load and strength design methods as well as the structural evaluation of existing bridges were developed. Results of the investigation were summarized in *NCHRP Research Results Digest 187: Distribution of Wheel Loads on Highway Bridges.* In addition the American Association of State Highway and Transportation Officials adopted the specification recommendations resulting from the project and published them as the AASHTO *Guide Specifications for Distribution of Loads for Highway Bridges.*

Under Project 12-26/2, a PC-based wheel load distribution software program was developed on the basis of grillage analysis methods. Modifiable for incorporation as a self-contained module into a complete bridge design and analysis package, the program should assist bridge offices in the automation of design.

NCHRP Project 24-6: Expert System for Stream Stability and Scour Evaluation

Many structures maintained by transportation agencies are constructed over waterways that are susceptible to various degrees of scour and stream instability. If not prevented or arrested, scour and instability can ultimately lead to failure, with possible loss of life and high cost of facility replacement. Relatively few experts exist who can use their judgment and experience to effectively address scour and stream stability problems, yet the solution invariably relies on such individuals. The objective of this research is to develop an operational, microcomputer-oriented, knowledge-based expert system to aid field personnel in evaluating current and potential scour and stream stability problems and identifying the need for countermeasures or additional detailed analyses. Much of this information may be applicable to automated design processes.

Pavements

NCHRP Project 1-32: Systems for Design of Highway Pavements

Pavement design requires consideration of many factors, including the effects of roadbed soil, climate, traffic loading, construction materials, and other design details and features on pavement performance and life-cycle costs. These considerations are being addressed through NCHRP Project 1-32 with a feasibility study on the development of a catalog of design features and an expert system. The objective of the design process is to identify pavement structures that will provide acceptable performance and economy over the intended design life.

Traffic

NCHRP Project 3-55: A Highway Capacity Manual for the Year 2000

Many NCHRP projects in the traffic area have a direct effect on the *Highway Capacity Manual.* Because the HCM can be laborious to use, many design offices use the Highway Capacity Software that is available through McTrans.

NCHRP Project 3-55 may provide a more automated approach to capacity analysis. The goal of the project is to make recommendations to the Transportation Research Board's Highway Capacity and Quality of Service Committee on the most effective formats and delivery systems for the next edition of the HCM.

NORTH CAROLINA
Robotics for Increased Safety in Highway Construction and Maintenance

ERICK F. LUCES, SUNGWOO MOON, RAMI A. RIHANI, and LEONHARD E. BERNOLD

A key advantage of robotic technology is the capability to replace humans with machines in dangerous work environments. Three projects in North Carolina demonstrate the way advanced technology can be used to provide operators with "smart" data, remove these employees from a dangerous work environment, and adapt existing equipment for use as platforms for robotic operation. The projects involve crane operations, pavement marker application, and bridge paint removal.

Using Robotic Technology for Crane Operations

Work crews of the Bridge Maintenance Division of the North Carolina Department of Transportation (NCDOT) must frequently perform maintenance operations that subject equipment to unusual loading conditions. Cranes, the workhorses of bridge maintenance crews, are most affected in these operations. The crews often use cranes to pull debris lodged in bridge piers or extricating piles. In past years, severe accidents involving boom and turret drive gear failures have been recorded. An accident involving the bending of a crane boom was reported recently. The repair of one of these booms can cost as much as $16,000. NCDOT currently supports a research project for the development of protective technologies to secure the department's fleet of 64 truck-mounted cranes. A crane equipped with sensors to measure behavior under various loading conditions is shown in Figure 1.

Two cases of critical loading conditions have been studied. One is the dragging of loads whereby the forces induced through the cable to the crane boom are not in a vertical plane, thus creating additional stresses. Visual inspection of crane booms revealed cable marks that indicate the occurrence of excessive dragging. The second case involves activities that result in abrupt extrication that may occur during the removal of piles, tree trunks, and other objects from the ground. When operators bring the crane into one of these loading conditions, they are operating in uncharted conditions. Allowable boom angles, loading capacities, or boom extensions were not developed with consideration for these types of operations (*1*). Consequently crane operators and foremen are obliged to rely on their perception of the situation to make decisions on the basis of their experience. These decisions have to be made in real time and often with insufficient and inaccurate information to complete a given job.

The foreman, who directs the lifting operation, has no means of predicting the exact mechanical effects (i.e., stress buildup in the boom cross section) produced during these abnormal and uncharted loading cases. Even though the operator can feel the response of the

FIGURE 1 NCDOT's sensor-equipped crane during experimental test.

Erick F. Luces, Sungwoo Moon, and Rami A. Rihani are Graduate Research Assistants; Leonhard E. Bernold is Associate Professor, Construction Automation and Robotics Laboratory, Department of Civil Engineering, North Carolina State University.

crane to these loading conditions to a certain point, the feedback from the machine is too inaccurate for decision making. Many accidents prove this point. Traditional overload protection systems provide a means for preventing damage to the boom but do not consider dragging or extrication cases, and some older cranes lack even these safety devices. The nature of the work and the demand for completing the job force the operator and supervisor to push the equipment to the limit.

Approach to Safer Crane Operations

To provide the information needed to operate the crane safely, a boom tip model with an anti-two block system was equipped with two types of electronic sensors (Figure 2). The vertically suspended pipe piece is a tip-switch that monitors the cable angle relative to the vertical. Directly attached to the boom tip are two accelerometers that measure acceleration in the vertical and horizontal planes.

A series of experiments has been performed duplicating the two critical loading cases (dragging and extrication) and the vertical lift by using a scaled-down version and a sensor-equipped crane. The sensors include (*a*) accelerometers, (*b*) pressure transducers, (*c*) load cell, (*d*) tip switch, and (*e*) inclinometers. The use of these sensory technologies allowed for the real-time collection of data during the loading experiments. Data on cable force and inclination, boom acceleration, hydraulic pressure, boom angle, boom extension, and crane level have been collected using these sensors.

The results of these experiments served as the basis for the analysis of the behavior of the crane under critical conditions. The data collected from each sensor are analyzed for patterns that are characteristic of each loading case. The establishment of patterns and threshold values representing the safe operation zones are the objectives of this analysis. These electronically recognizable patterns form the basis for the design of the control aid system.

The smart crane control support system presents an approach that keeps the operator involved. Sensory technologies can improve the operator's perception. Data on crane conditions can be collected from the sensors and fed to the microprocessor through an analog-to-digital converter. The microprocessor is programmed to continuously interpret the readings. The operator has the final decision-making power (Figure 3) (2).

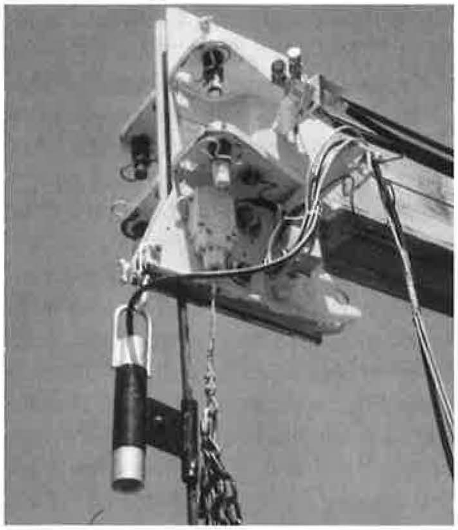


FIGURE 2 Electronic sensors mounted on crane boom tip.

One of the key functions of the microprocessor is to monitor the many sensors and to search for recognizable signal patterns. If the sensor readings during the operation exceed established threshold conditions, the control system can signal a warning message, a screen output suggesting a corrective action, and even the eventual shutdown of the crane.

A written log of crane conditions during the daily operations can be retrieved from the files created automatically by the microprocessor. This capability may have a positive psychological effect on the operator because it can prevent the operator from following inappropriate requests from the work crew.

Project Status

This system is being readied for field testing and a hierarchical control procedure has been devised. All the electronic devices, cables, power supplies, and the like have been hardened to survive the rough construction environment. Field tests were conducted in December 1994.

Telerobotic Raised Pavement Marker Applicator

The pavement marker placement process is time-consuming and can be hazardous. In a common scenario, a truck with a specially designed operator bay travels slowly along the road and stops at required intervals [e.g., every 12.2 meters (40 feet)]. An operator applies bitumen to the

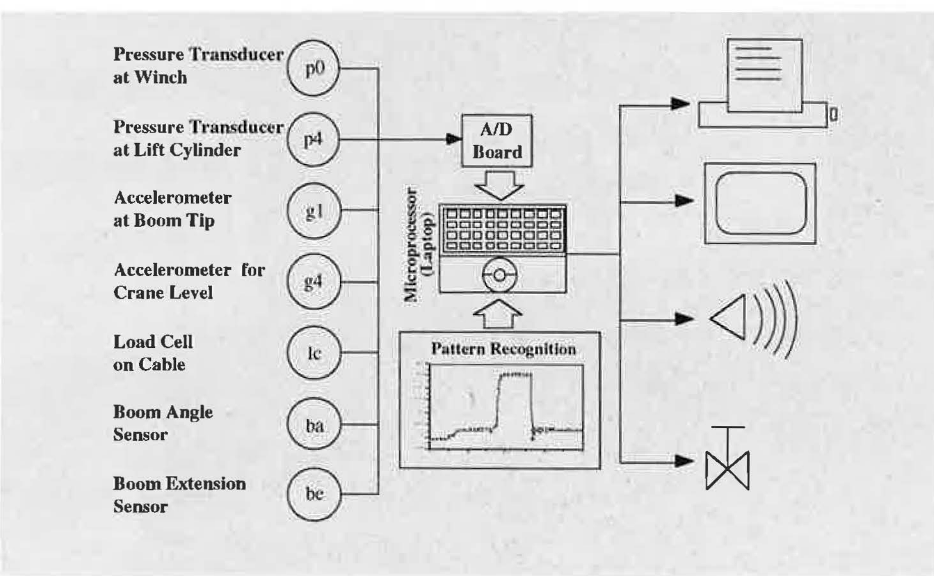


FIGURE 3 Analog control system for safe crane operations.

road via a hand-controlled dispenser and applies the marker on the bitumen by hand. This procedure requires the operator to extend a hand and an arm into oncoming traffic. The bitumen is approximately 400°F when applied, which provides another opportunity for operator injury. In addition the slow-moving truck necessitates lane closure, which represents a hazard for traffic.

Different approaches and technologies have been evaluated by experts from North Carolina State University, NCDOT, and a local contractor. In view of the mission to create practical solutions, the local contractor's current hardware (e.g., marker truck) was chosen for the new system. A critical aspect of this project was to draw from the experience of the contractor to use as a basis for field tests of different prototypes.

A team has been working on developing a telerobotic raised pavement marker applicator (TRPMA) since July 1993. The specific objectives of this project are to (*a*) test and evaluate the technical feasibility of creating a safer work environment for raised pavement marker application and (*b*) demonstrate the capabilities of advanced technologies in the area of highway maintenance and control.

System Design and Components

Removing the operator from the hazardous work bay is the most important step toward improving worker safety. The space occupied by the operator can be used to assemble an experimental system that is capable of applying the marker automatically. The first operable prototype was recently installed on one of the trucks provided by the local contractor. The TRPMA installed on a marker placement truck is shown in Figure 4. The side of the truck has been removed to allow space for the developed system. Also installed are the bitumen kettle and pump that feed the hot bitumen to the dispenser via a hose. The first two vertical marker stacks, which are pneumatically operated, can be preloaded to serve as a cartridge and may contain markers of various colors. The marker manipulator is moved, via a smart hydraulic cylinder, to the position of bitumen and marker placement. All actuators are controlled by a microprocessor through the use of electronic relays.

Because of the complexity of deciding on the position of each marker, a human-in-the-loop control architecture was chosen. Telerobotics provided an acceptable framework for the situation, in which an operator is physically separated from the equipment. The camera is mounted on the truck's front bumper to provide the operator, now sitting beside the driver, with a view of the marker placement operation (Figure 5).

The key to teleoperation is the interfacing of the camera with the smart cylinder that manipulates the bitumen dispenser. This telerobotic system is composed of a camera, a television monitor in the cabin, and a computer equipped with frame-grabber software and a mouse. While monitoring the operation and using a cursor appearing on the television monitor, the operator uses the mouse to select the position of the next marker. The cylinder then extends to the desired position before the bitumen is sprayed and the marker is placed automatically on top of the bitumen.

The current system requires the truck to stop every time a marker is placed. To eliminate the need for a stop-and-go operation and to increase productivity and traffic safety, a special mounting will be added that holds the marker and accelerates it in the opposite direction from that in which the truck is moving for in-motion marker placement.

FIGURE 4 Installation of telerobotic raised pavement marker applicator on truck.

Robotic Bridge Paint Removal System

Steel girder bridges deteriorate rapidly if they are not properly protected against corrosion. The protection includes paint application for bridge structures to stay in safe condition. Surface preparation is an important step that should be taken before the application of new paint. Preparation is required for removing interference material, increasing surface profiles, and washing away water-soluble salts to ensure the long-term performance of the coating system.

The presence of lead in the old paint coating represents a particular problem because it requires special attention in the removal process. Occupational Safety and Health Administration regulations have recently become more restrictive to protect the health and safety of workers and the

FIGURE 5 Camera mounted for teleoperation.

natural environment of the working area (4). An automated bridge paint removal system appears to be a promising approach that can free workers from hazardous working environments (5). The Robotic Bridge Paint Removal (RBPR) project, sponsored by the Federal Highway Administration, addresses this increasingly urgent problem in bridge maintenance.

Current Automation in Paint Removal Applications

Although the application of robotics to the painting operation is nothing new, its application to paint removal is a relatively new area. Southwest Research Institute developed an automated robotics system for aircraft paint stripping (5). The system consists of two robots, two robot controllers, a cell control computer, paint sensors, and bead blasting equipment. Various sensors are used to detect the availability of blasting materials, clearance of objects, location of the end point, and removal rate of blasting. Using the data input from the sensors, the robotic system controls the speed of the robot arms to ensure uniform cleanup regardless of the thickness of existing paint coatings.

Another automated blast system, called Auto Blaster, was manufactured by D&S Services, Inc. (6). This system, is a hoisted platform type and is operated either in an automatic or manual mode using wireless controllers. After blasting is finished, workers can do a final touch-up while standing on the platform.

Although not designed specifically for bridge paint removal work, LTC, Inc., developed an actuated system that is pneumatically powered. Movement is controlled in both vertical and horizontal directions by fingertip manipulation. The ease of control relieves workers of loading required for manually handling blast hoses. Valley Systems, Inc., has built an automated paint removal system based on a water jet technology. The approach takes advantage of a platform deck that is suspended by two cables on the flat surface of a large storage tank (4).

Design and Development of Robotic Bridge Paint Removal System

With a grant from FHWA and strong cooperation and support from NCDOT, a prototype RBPR system has been designed, built, and tested. One of the key advantages of this project was the adaptation of an existing bridge maintenance crane instead of the development of a new system. Retrofitting existing equipment could reduce system development costs and time and ensure economically acceptable solutions. The unique shape of bridge beams and the need for dust and debris control provided challenging design problems and required innovative solutions.

A schematic overview of the end-effector components in the RBPR system is shown in Figure 6. The selected system is composed of (*a*) a bridge inspection crane, (*b*) an actuated platform, (c) two sliding tables, (*d*) a robot arm, (*e*) a dust control mechanism, and (*f*) a sandblasting and vacuuming system. The third section of the crane boom was replaced for retrofitting. The actuated platform with the two sliding tables was built for positioning the robotic sand blast and dust control mechanisms.

Each element of the RBPR system is activated in sequential order to perform given tasks such as positioning of the platform end effector, spot cleaning of corroded steel beam surfaces, and containment of dust and debris. Control of the RBPR system is done by a vision system made up of a camera, a television monitor, and a frame grabber. Ultrasonic sensors provide distance data that are used for avoiding collision with any object under the bridge deck.

Preliminary Field Test

During the development of the RBPR system, several preliminary tests were conducted on a steel girder bridge to review

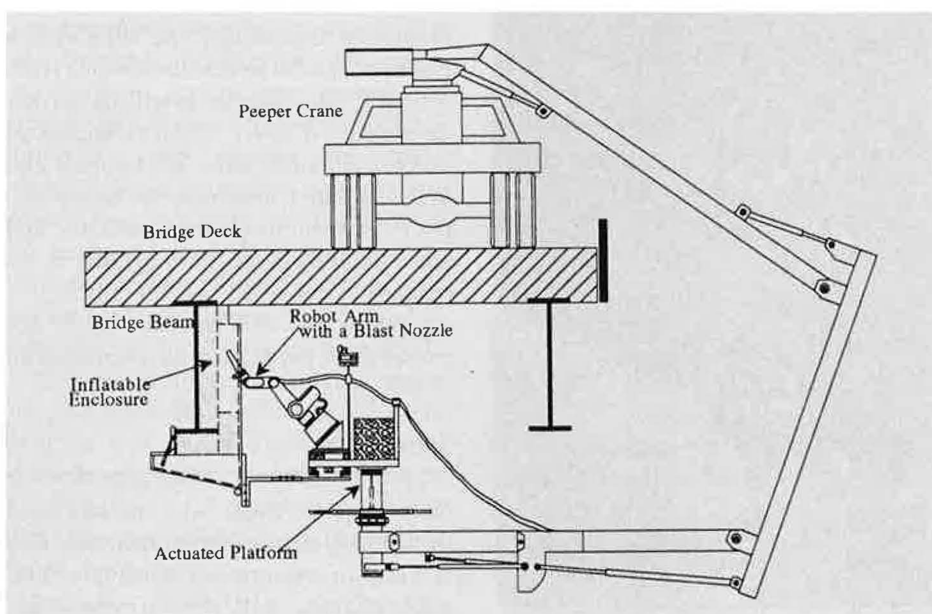


FIGURE 6 Overall view of Robotic Bridge Paint Removal system.

FIGURE 7 Deployment of Robotic Bridge Paint Removal system for field testing.

the feasibility of the conceptual design (Figure 7). The tests included containment of blast dust, actuation of end-effector components, and verification of the computer-integrated control architecture. These experiments demonstrated that vision-based telerobotic blasting is effective in the spot cleaning of corroded paint and that the enclosure mechanism can satisfactorily collect abrasive blast material. The prototype end-effector system is shown in action in Figure 8.

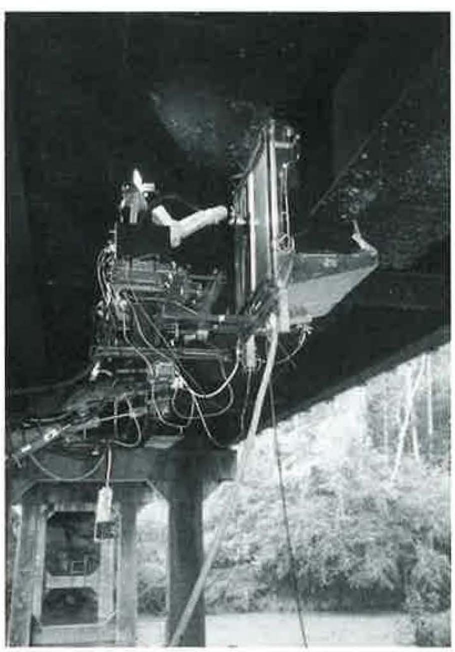


FIGURE 8 End effector in action under bridge deck.

Future Work

Because of its flexibility, the RBPR system can be expanded to execute various types of tasks. For example it will be further developed to cover different shapes of bridge structures such as channels and bracings. The system can also be retrofitted to perform inspection, washing, and spray painting. Such an integrated maintenance system will provide alternative solutions that will increase safety for workers, the public, and the environment.

Summary

New projects under way include field demonstration of a robotic excavator that is linked in real time to a spatial positioning system that will provide an interface with computer-aided design data. Another method that reduces the danger of hitting buried utilities during excavation and trenching is being researched. Close partnerships among academia, government, and industry are central to all the reported projects.

Acknowledgments

The TRPMA project was funded by NCDOT and its support is gratefully acknowledged. Also recognized is the assistance of Clark Pavement Marking, Inc., and the Instrument Shop of the Engineering Research Service Department at North Carolina State University. The combined expertise of the many participants was instrumental in moving the project ahead. The authors believe that such coordination between the system designer and the end user can significantly reduce project time and costs while ensuring the practicality of the result. The contribution of Daniel Bernd, an undergraduate student, is also recognized.

The RBPR project is supported by FHWA as a part of an Advanced Highway Research contract. Special thanks are due to Charles Woo of the FHWA Turner-Fairbank Highway Research Center, Jimmy Lee and Fred Mehfar of the NCDOT Bridge Maintenance Division, John Burns of the NCDOT Equipment and Inventory Control Division, and William Medford of the NCDOT Materials and Tests Unit. Also acknowledged are the many individuals at the NCDOT Equipment Maintenance Shop in their efforts to fabricate the RBPR system and Von Luhman, a graduate student in CARL, for his assistance in this project.

The Intelligent Control Aid for Safe Crane Operations project is funded by NCDOT and the expertise of the engineers from the NCDOT Divisions of Bridge Maintenance and Equipment/Inventory Control previously mentioned is acknowledged. Jerry Bagwell from the NCDOT Equipment Maintenance Shop contributed his knowledge of crane operation and maintenance to the project. Yong Bai, a graduate student in civil engineering at North Carolina State University, provided valuable programming services.

continued on page 34

Advanced Highway Maintenance and Construction Technology Applications

The Future Generation of Highway Machinery

THOMAS H. WEST, STEVEN A. VELINSKY, and BAHRAM RAVANI

The Advanced Highway Maintenance and Construction Technology (AHMCT) Center was established in 1989 to investigate the application of advanced automation and robotics to highway maintenance and construction. The center is jointly managed by the California Department of Transportation (Caltrans) and the University of California, Davis (UCD). Base funding is provided by Caltrans, the Federal Highway Administration, UCD, and other public and private sources.

Highway maintenance and construction methods have improved considerably during the past several decades, but they continue to be labor intensive, hazardous, and inefficient. The application of technological innovation and systems improvement can speed construction and maintenance task completion, reduce associated costs, and make highways safer for their stewards and for travelers. Accordingly AHMCT Center objectives include

- Enhancing the safety of highway workers and the traveling public,
- Improving the efficiency of highway maintenance and construction activities,
- Improving the reliability of highway infrastructure,
- Minimizing congestion delays caused by highway maintenance and construction activities, and
- Reducing the environmental impacts of highway maintenance and construction activities.

Thomas H. West is Electrical Engineer, Division of New Technology and Research, California Department of Transportation, Sacramento. Steven A. Velinsky and Bahram Ravani are Professors of Mechanical Engineering and Codirectors, Advanced Highway Maintenance and Construction Technology Research Center, Department of Mechanical and Aeronautical Engineering, University of California, Davis.

Research and development projects undertaken at the AHMCT Center are selected for their potential to meet significant challenges affecting safety, efficiency, and cost savings. The project life cycle begins with user surveys of perceived need and recommendation for service, process, method or equipment improvement, and innovation. Selected projects must meet the test of broad application and demonstrate strong potential for commercialization. Some projects may be pursued on their individual merit, provided the development is critically needed and independent and private research cannot be expected to bring the concept to commercial markets.

The preprototype research phase involves feasibility studies, cost-benefit analyses, and literature searches. Prototype development includes periodic design reviews and intensive evaluation by transportation maintenance and construction personnel.

End-user observations are incorporated into prototype improvements until a field-operational engineering prototype is developed that has been tested extensively in all environments by transportation workers. User comments and recommendations contribute to continued improvements until a reliable prototype is developed. Product manufacturers and marketing firms advance the product from its prototype stage to commercial marketability so that it can become a useful and cost-effective innovation of benefit to all public and private transportation organizations.

The center's research programs use emerging technology, including automation and robotics, to convert many labor-intensive, time-consuming, and tedious operations to safer, faster, and more efficient automated processes (*1*). Automation and standardization made possible through technological innovation improve productivity and reliability and reduce transportation system costs. The center's five technical areas, shown in Figure 1, and sample projects within these areas are described in the following sections.

Roadway Maintenance and Construction Technology

Maintaining the quality of highway surfaces and extending the time between pavement rehabilitation projects are major objectives of transportation agencies. Ensuring a safe environment for travelers by maintaining roadway markings and lane delineations is a related and critically important job. Typical maintenance and

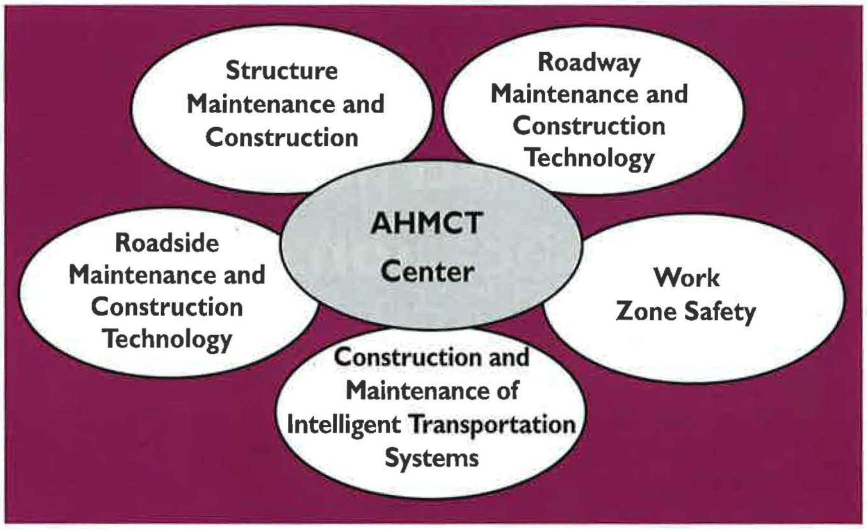


FIGURE 1 Technical areas of the Advanced Highway Maintenance and Construction Technology Center.

construction activities currently being addressed are pavement crack sealing and lane marking.

Automated Crack Sealing Machine

Crack filling and sealing is necessary to ensure roadway structural integrity and extend the time between major rehabilitation efforts. Conventional crack sealing operations can be dangerous and tedious. A typical sealing operation requires a large crew, which seals one to two lane-miles per day while exposed to traffic in adjacent lanes.

Through the support of the Strategic Highway Research Program and Caltrans, the automated crack sealing machine (ACSM) has been developed by UCD and Caltrans with contributions from private industry to improve efficiency, reduce costs, and enhance safety for workers and travelers (2,3).

The ACSM (see Figure 2) is a self-contained prototype vehicle for automatic identification, preparation, and sealing of roadway cracks. It can operate in two modes: sealing cracks entirely within a highway lane or sealing longitudinal cracks along the side of the vehicle. The ACSM's integrated system is completely modular and allows various combinations of subassemblies for sealing procedures that may differ from state to state.

FIGURE 2 Automated crack sealing machine.

The ACSM includes a three-axle truck with a line scan vision (video) system mounted on the front and a robot positioning system mounted on the rear. Computer systems are housed on the truck bed, as are peripheral support systems. ACSM is driven by various integrated subsystems that

- Detect the position and orientation of pavement cracks at the front of the vehicle,
- Monitor the relative position of the vehicle,
- Integrate all subsystem operations from start to finish,
- Position the crack sealant dispenser and other tooling along the crack,
- Determine the order in which cracks are sealed,
- Verify the presence of cracks, and
- Guide a submachine that seals longitudinal cracks.

The ACSM in a longitudinal sealing mode has been undergoing field testing and can perform longitudinal operations at speeds of more than 16 kilometers per hour. The integrated machine also has demonstrated ability to seal random and transverse cracks. Continued development will simplify its operation and make progress toward commercialization.

Robotic System for Roadway Stenciling

The current method used to apply roadway symbols and signs requires manual placement of a stencil on the pavement, followed by either the application of paint or torch-down of a thermoplastic material. Both procedures expose maintenance employees to traffic and possible injury and are slow and labor intensive.

A robotic system for stenciling roadway markings can improve efficiency and worker safety. By using a spray gun guided by a robot manipulator, a single operator will be able to plan the operation on-site, position the vehicle for proper alignment, and complete the stenciling operation from the cab of the maintenance vehicle. The system will paint different sizes of various symbol configurations. System versatility will be obtained through the use of advanced robot path planning methods (4).

Initially this project has focused on painting target marks for photogrammetry, a survey method that uses aerial photographs of the roadway. The target marks are used for the calibration of vertical positions and are currently painted manually by survey crews. A black square is painted for the base image and an X stencil is placed on the base and painted in a contrasting color, usually white. A two-person crew requires two to three days to paint target marks on one mile of highway.

The prototype system (Figure 3) is composed of a gantry robot (*x-y* plotter) and is designed to pass two rows of painting nozzles (one white, one black) over the asphalt surface to complete the photogrammetry mark. Motors and pneumatic cylinders are used to lift the stenciling apparatus from the truck to the ground, thereby eliminating the need for workers to be exposed to traffic.

FIGURE 3 Sign-stenciling robot prototype.

Laser-Guided Lane Striping System

Each year, Caltrans expends some 85 person-years of labor to paint 76,000 kilometers of highway lane stripes. The process is painstaking. The driver must guide the paint vehicle precisely, using multiple sights and mirrors so that outrigger-mounted paint guns follow existing lines. Preoccupied with the task, the driver may not be fully aware of fast-moving and constantly changing traffic conditions. A crew member in the rear of the vehicle selects the striping patterns and triggers the paint guns. Both tasks are tedious and fatiguing.

The AHMCT Center is automating part of the lane striping process to improve efficiency, reduce the impact on traffic flow, and enhance safety. Laser-guided automation of the outrigger guidance system will increase driver awareness of surrounding traffic and reduce fatigue. Automation of the paint gun triggering process will enable the second crew member to perform other tasks. Increased productivity and greater safety will result, and striping accuracy will be ensured.

The system will be able to position the paint gun outrigger and trigger the correct paint nozzles to duplicate existing stripes. It must be able to identify pavement stripes that have degraded by 50 percent, provide accurate guidance response at speeds of up to 64 kilometers per hour, and maintain tracking tolerances of 13 millimeters laterally and 102 millimeters longitudinally.

Roadside Maintenance and Construction Technology

Transportation agencies are also responsible for the maintenance of highway rights-of-way and infrastructure. Necessary tasks include construction of the roadside and the maintenance activities of roadside vegetation control, landscaping, litter and refuse removal, graffiti abatement, and the cleanup of hazardous material spills.

Landscape maintenance research is aimed at reducing the use of water for irrigation and herbicides for vegetation control. Biogenetic technology offers promise for the development of a wide variety of landscape plants that require less maintenance.

Employee exposure to traffic can be reduced through the use of automated litter pickup equipment. Efficient and fast methods for graffiti removal will alleviate personnel requirements significantly while minimizing the use of hazardous cleaning chemicals.

Smart Herbicide Applicator

Vegetation control on transportation system right-of-way is a necessary component of Caltrans' highway maintenance program. Uncontrolled weed growth impedes driver visibility, fuels grass and forest fires, and contributes to pavement degradation. Caltrans uses an integrated system of vegetation control that includes mechanical methods; use of low-growing, drought-tolerant, and fire-resistant plants; and application of herbicides. The development of an intelligent herbicide application system will help Caltrans meet its herbicide reduction objectives and control vegetation that cannot be treated effectively in other ways.

This project is intended to develop a method of herbicide application that targets specific plant materials, avoids others, and applies precisely required amounts of herbicide accurately and without overspray. The system incorporates the following technologies:

- *Vision sensing* is used to detect green plants. The targeted field of view is up to 2.4 meters perpendicular to the traveling vehicle.
- *Image processing* is used to identify and characterize detected plants. Leaf sizes

as small as 1.25 square centimeters can be detected by the vision system. The location and size of a plant can be approximated while the vehicle is in motion. These data are processed by a control system to actuate spray nozzles.

- *Speed-compensated control system* uses data from the image processor and a radar-based speed detector. The ground speed detector is necessary to determine the trajectory of the herbicide and the nozzle action required for targeting. The combination of these data will enable the controller to specify the exact moment to actuate the appropriate applicator nozzle so that the detected plant is targeted.
- *Rapid-response spray nozzles* on a boomless vertical nozzle bank precisely direct the application of herbicides to plant tissue and reduce overspray.

The integrated components have already been demonstrated, and integration into an existing Caltrans vegetation maintenance vehicle is under way. The prototype demonstration system is shown in Figure 4. The intelligent herbicide application system will efficiently operate up to 16 kilometers per hour. Regional vegetation control crews will be involved in the evaluation of the system—a critical step in developing equipment that will be acceptable and usable by the maintenance work force.

FIGURE 4 Smart herbicide applicator prototype.

Caltrans intends to reduce its use of herbicides by 50 percent by the year 2000 and by 80 percent by the year 2012. This project will help to achieve that commitment and reduce highway maintenance costs.

Laser Removal of Graffiti

The marking of noise barriers, signs, buildings, bridges, and other objects is an excessively costly problem for Caltrans and others who maintain public and private property. Such graffiti can create significant hazards by rendering signage unreadable and distracting drivers.

Current methods for graffiti removal include chemical cleaning, repainting, sandblasting, water blasting, or replacing or removing the vandalized object. Workers may be exposed to hazardous chemicals and to traffic during these operations. The task is labor intensive and the methods and chemicals used often damage treated surfaces.

The feasibility of removing graffiti from transportation facilities using laser irradiation is under study at the AHMCT Center. The laser method of removal does not require solvents or other materials nor does it result in environmentally harmful byproducts.

Development of an effective laser graffiti removal system begins by first examining the efficiency of laser wave and pulse lengths on graffiti removal. Each graffiti tag (spray paint, crayon, etc.) and underlying surface (concrete, cinder block, brick, metal, wood) will be considered and the best laser technique for each situation recommended. Researchers will consider various continuous- and switched-wave lasers and frequencies, modulation, and power levels. The project goal is the development of a working prototype. The high demand for a functional product from this project is nationwide. Signs with tags removed by the laser process are shown in Figure 5.

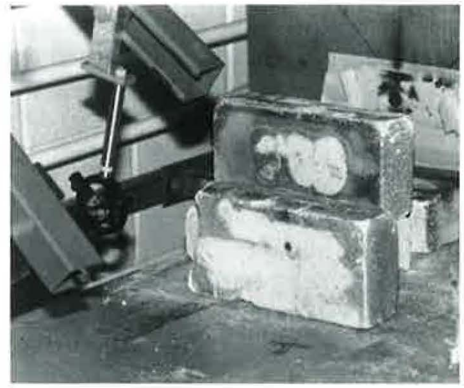


FIGURE 5 Highway sign pieces with tags removed by laser.

Teleoperated Hazmat System

Caltrans' responsibility in highway maintenance extends to the removal and disposal of unidentified, potentially hazardous substances spilled on roadways. In current practice, emergency response teams attempt to identify spills with binoculars and spotting scopes from a safe, remote site. Occasionally, a spilled container label or placard is within sight, and the substance can be identified and removed quickly. However if the substance is unknown and cannot be positively identified by remote visual inspection, additional procedures and specialists must be employed. Maximum safety procedures must be practiced because fumes from toxic spills can be lethal. Emergency response teams consist of six individuals: two are responsible for obtaining a sample of the spilled substance, two are responsible for decontamination, and two are available for backup.

Current procedures are time consuming and inherently dangerous to workers and travelers and cause significant traffic delays.

Two prototype hazardous spill sampling vehicles have been developed in conformance with detailed specifications from Caltrans hazardous material coordinators. Both vehicles are remotely controlled and equipped with video monitoring systems for close-range inspection of the spill site. Each vehicle can retrieve samples (solids and liquids) and monitor and record activities during the emergency response operation. Instrumentation aboard each vehicle can report whether contamination is confined or spreading. A teleoperated hazmat vehicle is shown in Figure 6.

Each vehicle is equipped with a full pan-and-tilt video camera. Design specifications require a minimum battery life of

30 minutes, shock-mounted drive wheels, explosion-proof motors, a sealed exterior for ease of decontamination, and the capability of being retrofitted for additional air-monitoring equipment (photo ionization). Through the use of these vehicles, the time to obtain material samples can be reduced to about 15 minutes and protective clothing requirements are reduced to Level C.

The next step in this project is the design of a remote-controlled laboratory, which will receive the samples collected by the vehicles for testing and identification. Key issues in the design include methods for identifying unknown substances, complexity and functionality, and the division of labor between the remotely controlled hazardous material laboratory and its human operator.

Structure Maintenance and Construction

The development of methods and equipment for rapid and remote inspection of bridge components and other structures is critical to maintaining the safe condition of deteriorating transportation infrastructure. The nation's large inventory of aging elevated structures mandates frequent and detailed inspections using equipment of increasing sophistication. Efforts focus on the development of products that will allow remote inspection of structural facilities, reduce human risk, and improve efficiency.

Caltrans bridge inspectors must frequently examine California's highway bridges and other structures to identify fracture-critical cracks before they become safety problems. Conventional methods involve the physical positioning of an inspector by the hydraulic telescoping arm of a "snooper" truck, thus providing visual access to otherwise inaccessible bridge components. The process is time-consuming, dangerous, and may be affected by poor lighting conditions.

A robotic aerial bridge inspection platform is under development that will make bridge inspections safer, faster, more efficient, and less expensive. This unmanned tethered robot platform will fly and inspect critical locations from a ground-based site through the use of a device to enable remote video inspection and computer image enhancement.

The first phase of this project has produced a remote-controlled flying platform (Figure 7) on which the inspection instrumentation can be mounted. The development of a more sophisticated pilot control system is under way. The flying platform is capable of vertical takeoff and landing and will be equipped with a high-resolution video camera. The platform is designed with unique, electrically driven ducted-fan technology. For added safety, there are no exposed moving parts. With this system, the camera can be positioned within 0.6 meters of the critical bridge component.

The aerial system includes a single ducted vehicle with an exterior diameter of 560 millimeters, a height of 580 millimeters, and a weight of approximately 180 Newtons. Electric power is supplied through a 30-meter power cable, providing 300 volts DC to operate two 4.5-kilowatt electric motors. The cable also carries control signals and video images through fiber-optic lines. Each motor drives a set of five fan blades and creates sufficient thrust to lift and control the vehicle and a 90-Newton payload. The vehicle is automatically stabilized through the use of onboard attitude sensors.

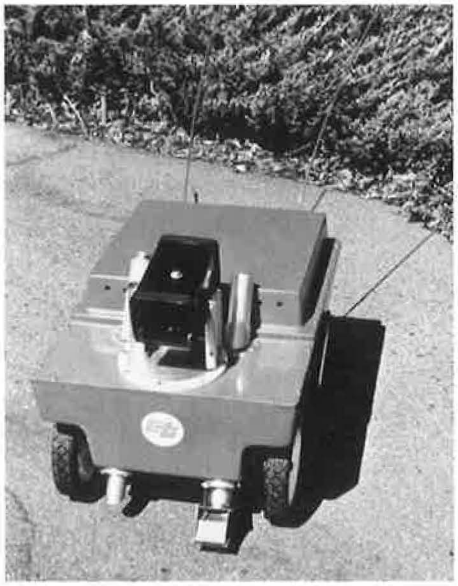


FIGURE 6 Teleoperated hazmat retrieval vehicle.

FIGURE 7 Aerial robotic platform.

The Image Enhancement Ground-Based System (IE-GBS) obtains video signals from a color RS-170 camera mounted on the remote-controlled aerial platform and the video camera can be panned and tilted to see from any angle. The IE-GBS consists of a computer and associated equipment with the capability for real-time display of images received from the inspection camera. The system acquires, stores, and processes images and can highlight specific features so that cracks and structural deformities can be readily identified. The benefits of this project include (*a*) enhanced images that help in locating structure cracks, (*b*) improved safety for inspection crews, and (*c*) image storage for review following inspection.

Other potential applications for the aerial platform and IE-GBS range from power line and building inspection to police surveillance.

Work Zone Safety

Many safety devices and procedures have been developed to protect line and field workers, including protective head gear, brightly colored garments, safety cones, and lane closure procedures. These and other products and procedures have been adopted by the construction industry with life-saving success.

The development of efficient, compact computers and intelligent sensors is leading toward the development of more sophisticated and active life-saving products. These items have the potential to perform such tasks as warning highway workers of the intrusion of traffic into the work zone and the approach of heavy equipment.

Teleoperated and Automated Maintenance Equipment Robotics (TAMER)

The use of heavy equipment such as crawler tractors, dozers, and loaders is crucial to highway maintenance. These machines are used in hazardous operations such as repairing highways after an avalanche, clearing landslides, cleaning up hazardous materials, and clearing snow. In such operations, in which soil and snow banks are unstable, road boundaries unrecognizable, or toxicity of potentially hazardous spills unknown, operators work in a high-risk environment. Teleoperated machines could perform many of these jobs and reduce worker exposure to dangerous conditions.

The objective is to design and construct a teleoperated or remotely controlled system to operate heavy-duty equipment from a remote site. The concept allows normal equipment operation during regular use. Typically the use of remote control has proven effective in removing personnel from potentially hazardous situations at the expense of reduced productivity. The goal is to restore lost productivity and improve efficiency through automation.

A remote-control package for a front-end loader has been developed with the collaboration of a company experienced in both remote vehicle control and secure communication systems. The communication and control system includes a microcontroller-based operator control unit, a full duplex spread spectrum RF modem capable of operation up to 19.3 kilobits per second at a range of up to 488 meters, and an on-vehicle, computer-based control system. The radio remote-control package uses a pair of transceivers to implement two-way communication. Two portable remote stations, a backpack mount and a palletized truck bed mount, have been successfully developed and demonstrated. The prototype system in operation with the truck-based operator station are shown in Figure 8.

FIGURE 8 Teleoperated and automated maintenance equipment robotics operated from backpack-mounted controller.

Tethered Mobile Robot

Many highway maintenance operations currently use materials and tools attached to or supplied from a support vehicle. For example, roadway crack sealing operations require maintenance personnel to apply hot liquid sealant from a dispenser wand. The wand is attached to a vehicle platform supporting equipment that melts the sealant and delivers the material to a dispenser tip. The operation is often slow and inefficient, impedes traffic flow, and exposes workers to potential injury. Other maintenance operations require power tools that depend on remotely located energy sources, such as vehicle-mounted generators, compressors, or engines.

Conventional robots have a comparatively low-load capacity in relation to their weight. Highway maintenance tools (e.g., pavement routers, paint nozzles, and the like) are heavy and exert extreme forces during operation. Furthermore, commercially available conventional robots usually perform repetitive manufacturing tasks, simply moving objects from one location to another. Highway maintenance operations are generally more complex and require tooling to follow paths that do not conform to preset patterns.

Work is being directed toward the development of a wheeled mobile robot system for the requirements of highway maintenance and construction tasks (5). The devices are called tethered mobile robots (TMR) because a tether attaches them to the support vehicle for power and supplies.

A scaled-down prototype TMR has been built to determine mechanical system and control specifications for operational models. Scaled prototype testing has led to the design and fabrication of a full-sized TMR capable of numerous demanding operations such as crack sealant dispensing (see Figure 9). A larger model is under design to accommodate high-load applications such as pavement routing.

A three-wheeled, differentially steered configuration is used to satisfy motion and tracking requirements. Such a configuration is robust and provides necessary tractive force. An instrumented passive mechanical link is used to measure the relative position of the TMR with respect to the support vehicle and to provide a means for material and power delivery. The control architecture is based on the latest mechatronics technology, which allows versatility coupled with rapid system response. The unique aspects of this robot are the control architecture, the relative position measurement system, and its design for high loads.

FIGURE 9 Tethered mobile robot.

Construction and Maintenance of Intelligent Transportation Systems

As transportation agencies implement more technologically advanced transportation systems, construction and maintenance operations will become more complex. Accurate equipment positioning, frequent testing, and rapid repair of control and communication instrumentation will be critical to automated transportation system construction and maintenance. Future maintenance of automated intelligent highways will be performed in an environment that supports more vehicles moving at higher speeds. Recent advances in designs for automated assembly, manufacturability, and life-cycle design justify the evaluation and development of new concepts for automated construction and maintenance of the transportation infrastructure.

Automated highway systems (AHS), often called smart highways or intelligent transportation infrastructure, integrate a variety of communication and control systems to make travel safer and more efficient. An AHS may include computer-driven networks and a complex array of sensors and data transfer systems that create an automated, intelligent relationship between vehicles and the transportation infrastructure. The success of such automated highways depends on development of system architecture (*6*), operational protocols, and maintenance and construction technology.

The objectives are to identify and analyze issues related to the construction, maintenance, and operation of smart highway systems in California's urban and rural environs. Examined are the human resources and management requirements for automating transportation systems. The research seeks to resolve the following specific AHS maintenance requirements:

• Identify functional components and technologies in a generic AHS configuration,
• Identify existing and evolving maintenance functions and operational requirements for each of the component technologies, and
• Develop an architecture for maintenance and operational functions.

Related tasks are necessary for the automated construction of an AHS and are included in the research program:

• Develop a system architecture for AHS construction,
• Analyze modularity and configuration potential of AHS designs,
• Analyze and evaluate the application of automation and robotic technologies, and
• Develop specifications and requirements for AHS construction.

Acknowledgments

The authors gratefully acknowledge Caltrans and FHWA for their generous support of the Advanced Highway Maintenance and Construction Technology Center.

References

1. Ravani, B., S.A. Velinsky, and T. H. West. Requirements for Applications of Robotics and Automation in Highway Maintenance and Construction Tasks. In *Proc., SPACE '94, ASCE Conference on Robotics for Challenging Environment,* 1993, pp. 356–364.
2. Velinsky, S.A. Heavy Vehicle System for Automated Pavement Crack Sealing. *Heavy Vehicle Systems, Series of the International Journal of Vehicle Design,* Vol. 1, No. 1, 1993, pp. 114–128.
3. Velinsky, S.A. *Fabrication and Testing of Maintenance Equipment Used for Pavement Surface Repairs.* Final Report of SHRP H-107A, Strategic Highway Research Program, National Research Council, Washington, D.C., 1993.
4. Kochekali, H., and B. Ravani. A Feature-Based Path Planning System for Robotic Stenciling of Roadway Markings. In *Proc., SPACE '94—ASCE Conference on Robotics for Challenging Environment,* 1993, pp. 52–60.
5. Winters, S.E., S.A. Velinsky, D. Hong, and K. Yamazaki. A New Robotic System Concept for Automating Highway Maintenance Operations. In *Proc., SPACE '94—ASCE Conference on Robotics for Challenging Environment,* 1994, pp. 374–382.
6. Lasky, T.A., and B. Ravani. A Reference Architecture and Classification for an Automated Highway System. In *Proc., First World Congress on Advanced Transport Telematics and Intelligent Vehicle Highway Systems,* 1994.

Laser Videodisc Technology Meets Changing Operational Demands

Many state transportation organizations are searching for new technologies to provide quick and accurate collection, verification, and analysis of data to fill the void caused by reductions in staff and increases in work load. The Connecticut Department of Transportation has met this challenge by using laser videodisc technology to provide information and data for the department's operations since 1984. Developed in cooperation with the Federal Highway Administration, the technology was introduced to improve the accuracy, efficiency, and safety of data collection in ConnDOT's pavement management system.

Problem

ConnDOT has recently undergone a 20 percent reduction in personnel, although the work load has increased in response to expanding operational requirements, legislative mandates, and public involvement. If required data on the physical characteristics of a roadway are not available in existing files or data bases, one or more individuals are sent to gather the information needed. Manual collection methods typically range from a simple drive-by survey to the dispatch of a survey crew with engineering equipment to record detailed measurements. The costs of manual data collection are high because of labor and travel costs.

Solution

To compensate for staff reductions and increased work loads, ConnDOT has employed its photolog videodisc image system, which contains images of the entire 6300 centerline kilometers (3,900 miles) of state-maintained highway network. Two photolog vans gather photographic images of the pavement and roadside as well as geometric data at 16-meter (0.01-mile) intervals. While filming, sensors located in the van generate an array of data including route number, direction of travel, roadway cross slope, compass reading, date, time, horizontal and vertical curvature, roadway roughness, grade, side friction, and vehicle speed. The images are stored on a laser videodisc that resembles a 305-millimeter- (12-inch-) diameter silver phonograph record. In effect it is a larger version of the compact discs used in home audio systems, personal computers, and commercial photodiscs. All images and related data for the entire state- owned roadway network are contained on 15 videodiscs. These images are a combination of windshield and close-up views of both pavements and appurtenances.

The advantages of the videodisc system are random accessibility, storage density, and durability. In addition, the ability to control the videodisc player with a personal computer enables retrieval of a particular highway photolog image or a series of images in a few seconds. Using high-resolution computer graphics to generate and overlay precisely located grid lines on the photolog image, an operator can easily measure numerous roadway features.

The videodisc system was developed in-house using off-the-shelf components. The process automates simple, low-level, highly repetitive tasks, yet retains operator intervention capability and control at the decision-making level. For example, the retrieval and viewing sequence of photolog images used to evaluate pavement condition is automated, but the actual distress evaluation is left to trained technicians familiar with pavements. The photolog system allows completion of tasks that previously were more difficult to complete manually. For example, gyroscopes mounted in vans can record information used to calculate roadway curve radii and rated speed limits and measure bridge clearances, heights of light poles and signs, lengths of guiderail, and sign offset distances.

Application

Photologging and videodisc production have been performed annually for the state-maintained roadway network for more than 10 years. Pavement rating from videodisc images began in 1987 and has formed the basis for the annual list of ConnDOT paving projects. This automated system has become an integral part of the department's operations.

Use of the photolog system has expanded beyond the pavement management system to address information needs such as roadway inventory, sign/signal inventory, research and special studies, public hearings, court cases, insurance claims, traffic accident studies, geometric studies, design improvements, hazardous-obstacle identification, railroad-crossing inventory, roadway-access determination, bicycle studies, location of roadway appurtenances, utility location, right-of-way review, bridge conditions, pavement-marking surveys, and maintenance. The photolog stations are used for enquiry, measurement, analysis, review, and reporting in the daily operations of many units within ConnDOT. Twenty photolog retrieval stations distributed throughout ConnDOT facilities are used daily by department and Federal Highway Administration employees and the private sector. Private and public sector requests for photolog images from the system each average about 300 per month.

The photolog at ConnDOT is easy to use and widely accepted. A growing approval of and familiarity with this technology has enhanced job performance and satisfaction. Technological and implementation goals must be realistic and flexible enough to change with the needs of the organization. Automation must not be seen as a quick fix to a problem but as a tool to be used and maintained by the organization over a period of time.

CONNECTICUT DEPARTMENT OF TRANSPORTATION

Connecticut Department of Transportation photolog laser videodisc workstation.

Benefits

The direct benefits of the photolog videodisc system include reductions in travel expenses and labor costs for various tasks. The results of its use include higher productivity, a safe and comfortable work environment, and the ability to view field conditions from the office. The photolog system has ancillary benefits such as allowing tasks to be "re-engineered." One employee can use photolog images, geometric data, and computer programs to complete in an hour a task that may have taken a two-person field crew a day to accomplish.

With the wealth of pictorial and numeric data available, new problem investigation methods have been developed. For example, instead of evaluating only the current pavement condition when determining paving priorities, pavement distress images and data for several years can be analyzed. FHWA research engineers have used the system extensively to measure sign entrance angles.

Information obtained from the photolog system has eliminated the need for 80 percent of field trips. When compared with traditional field trips, photolog use generates an estimated \$1 million savings annually in travel and labor costs and more than 200,000 miles of reduced vehicle travel. This figure does not include the additional savings of safety and convenience that the photolog system offers. Recent efforts to implement a new inventory system for the state's 170,000 highway signs established that the cost of the photolog system would be less than \$0.5 million compared with the inventory system, which would cost \$1.3 million if traditional data-collection methods were used.

The number of photolog stations is expected to increase as additional units within ConnDOT and the public and private sectors recognize the capabilities of the system. Moreover the rapid evolution in computer-based imaging technologies is underscored in the significant cost reduction of a retrieval station (i.e., \$30,000 during the period 1984–1993 to as little as \$4,000 in 1994 to retrofit a desktop PC). The expansion in the number of photolog stations is consistent with the philosophy under which the technology was developed: to share information with as many users as possible.

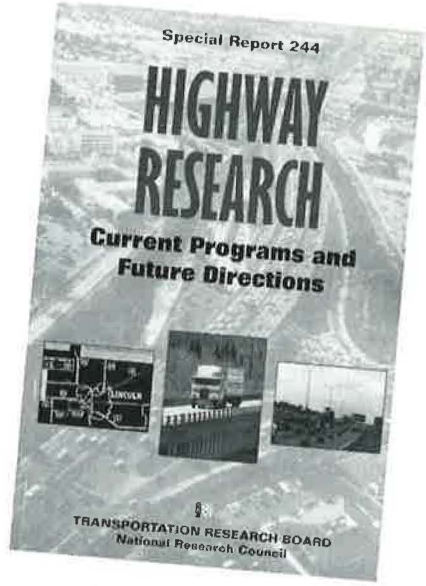
For further information contact Charles E. Dougan, Director of Research and Materials, Connecticut Department of Transportation, 280 West Street, Rocky Hill, Connecticut 06067.

Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418 (telephone 202-334-2952).

New TRB Report

HIGHWAY RESEARCH

Current Programs and Future Directions



TRB *Special Report 244—Highway Research: Current Programs and Future Directions* is available from the Transportation Research Board.

The Research and Technology Coordinating Committee (RTCC), organized by the Transportation Research Board in 1991, provides the Federal Highway Administration with an ongoing independent assessment of its research, development, and technology efforts to develop broad-based priority recommendations for the years ahead. In examining U.S. highway research and technology (R&T) activities, RTCC found them to be highly decentralized and diversified: several federal agencies, each state highway agency, private companies, universities, and various public and private groups sponsor or conduct highway R&T programs. The committee's report, *Highway Research: Current Programs and Future Directions,* provides a single source of information about highway R&T programs, activities, and expenditures.

The three principal public-sector highway R&T programs, the FHWA program, the State Planning and Research (SP&R) program, and the National Cooperative Highway Research Program, are described in the report. These programs and their 1993 expenditures are examined in terms of eight categories of R&T activity (see accompanying box). The categories were defined by committee consensus to reflect current research priorities. By focusing on 1993 expenditures the committee developed a "snapshot" of R&T activities; aware of the limitations of this approach, the committee recognized that significant changes have already taken place that should be considered in any discussion of current and future programs. Consequently the steps taken to enhance weak areas and aggressively pursue strong ones are also discussed in the report. Ample evidence exists to indicate that the highway research and development programs described are dynamic and that change is fundamental to their nature. Also presented is the committee's vision of appropriate new directions and emphasis areas for highway R&T.

Major Public Sector Programs

FHWA is the single largest sponsor of highway research; it spent $168.5 million on research and $32.5 million on technology transfer activities in 1993. Its research focuses on traditional topics related to highway engineering such as pavements, structures, and materials, as well as planning, environment, and highway financing issues. In recent years the agency has taken the lead in the search for improving highway capacity and safety through the application of computer, information, and telecommunications technologies. FHWA also continues the large-scale, 20-year pavement test initiated under the Strategic Highway Research Program.

The Intermodal Surface Transportation Efficiency Act of 1991 redefined the Highway Planning and Research program as the SP&R program, required states to spend 2 percent of their total federal-aid highway apportionments for planning and research, and specified that at least one-quarter of these funds be spent for R&T. In 1993 states spent approximately $79 million under this program, compared with $25 million in 1991 and $69 million in 1992. State research studies generally emphasize practical solutions for quick application to current problems. In addition states provide technical assistance to regional and local transportation agencies, perform materials and equipment testing, and support staff development and training with SP&R research funds.

States can pool SP&R funds to address problems of common interest. The most significant pooled-fund research program is NCHRP, which is administered by the Transportation Research Board. NCHRP was created soon after construction of the Interstate system began, when many states experienced similar problems related to design and construction. In 1993 NCHRP funding was about $15 million, nearly twice its funding for previous years. NCHRP projects address problems of common interest to many states and are designed to produce results for immediate application. The American Association of State Highway and Transportation Officials' Standing Committee on Research selects NCHRP project topics, and TRB convenes expert panels that oversee the selection and work of a research contractor for each topic.

Private Sector Highway Research

Private sector research consists of many individual programs conducted or sponsored by engineering associations and industry groups involved in highway transportation and by companies that design and construct highways and supply highway-related products. Annual research funding by highway-related associations and foundations is greater than $20 million. Although details about research conducted by individual companies and funding levels are difficult to obtain—because of the hundreds of companies involved and the proprietary nature of the work—such funding is not insignificant. For example, information on companies that manufacture construction equipment indicates that the portion of their 1992 research budgets attributable to highway construction equipment (based on sales volume) is about $65 million. Private sector research has a large impact on the industry that could be even greater if it were better coordinated with the public sector programs.

Estimated R&T Program Spending in 1993

Estimates of R&T spending by category in FHWA, NCHRP, and SP&R programs in 1993 confirm that the FHWA R&T program focuses on short-term research aimed at many topics, remains true to its modal mission, and supports a substantial amount of technology transfer and field applications (see Table 1). Breakthrough research topics at FHWA were dominated by intelligent transportation systems. Two categories considered important by the committee, U.S. transportation system issues and intermodal issues, are candidates for additional funding. NCHRP 1993 spending reflects the priorities of state officials who select the research topics. Recent priority topics include intermodal issues—a growing concern in states with ports—and breakthrough research, as evidenced by the inauguration of NCHRP's Innovations Deserving Exploratory Analysis (IDEA) program, which supports innovative research. The mapping of state highway research and development expenditures for 1993 underscores state interest in incremental research and problem solving. Because state highway departments are the operating agencies closest to users, they often need immediate answers to technical questions.

Future Highway R&T Program Directions

The highway R&T program has a solid foundation. Highway research has been most effective when focusing on efforts to reduce costs and improve performance for everything from asphalt pavement to traffic signal systems. Funding for R&T has risen in the past decade in real terms, and support for breakthrough research has increased. Highway industry leadership strongly supports R&T activities, and public/private partnerships are increasing. Nevertheless to ensure an improving and evolving highway R&T program, changes are needed.

Because several areas of highway research have potential for large payoffs, program funding should be increased. In addition, more partnering among public agencies and cooperative public/private efforts should be undertaken. Further, because revolutionary changes resulting from new technologies, materials, and

TABLE 1 Summary of Expenditures for Highway R&T Program, 1993

	EXPENDITURE [$ millions (%)]			
CATEGORY	FHWA[a]	NCHRP	STATES[b]	TOTAL[c]
1. Incremental Improvements in Highway Performance and Costs	118 (59)	4.2 (56)	36.2 (54)	157 (57)
2. Breakthrough Research To Improve Highway Performance and Costs	10 (5)	1 (13)	0	11 (4)
3. Reassessment of U.S. Transportation System and the Role of Highway Transportation	0.82 (1)	0.3 (4)	0.07 (<1)	1.2 (<1)
4. Compliance with Government Regulations and Policy Proposals	18.3 (9)	0	0.3 (<1)	19 (7)
5. Improvements in Intermodal Transportation Services that Involve Highways	0.5 (<1)	0.8 (<10)	0.4 (<1)	1.8 (1)
6. Transfer of Promising Research Findings to Field Application	22 (11)	1.1 (15)	3.7 (6)	26.4 (9)
7. Education and Training of Highway Professionals	19 (10)	0.1 (1)	10 (15)	30 (11)
8. Other Research, Technical Support, and Testing	12 (6)	0	16.7 (25)	30 (11)
Total[d]	201	7.5	67.4	276

[a]Federal funds for the Local Technical Assistance Program (LTAP) are included in the education and training category.

[b]State data are based on a sample of 15 states that comprise more than 50 percent of SP&R spending. State expenditures have been factored upward to 100 percent of SP&R funding. State LTPP and TRB Research Correlation Service contributions have been included in the education and training category.

[c]Total includes actual FHWA and NCHRP expenditures and estimated total state expenditures based on a 50 percent sample.

[d]Errors in sums due to rounding.

SOURCE: FHWA, TRB, personal communications with state highway department officials.

methods—which often involve a radical departure from conventional approaches—hold great promise, more exploratory, high-risk research should be undertaken. Initiatives aimed at ensuring that other federal agencies, as well as state and local agencies and the private sector, are active partners in highway R&T efforts, should be expanded to ensure the largest possible leveraging of the overall research investment.

The future highway R&T program should also take a broader view than it has in the past, encompassing the interactions among highways, other transportation modes, and nontransportation societal objectives as well as other factors, such as maturing telecommunications technologies, that are affecting many aspects of transportation. Finally, the barriers to innovation need to be addressed comprehensively by the entire highway industry so that attitudes and practices that stifle innovation can be overcome. Successful implementation of research products requires involving the end users of innovation in the research process as early as possible, beginning with project planning. In addition, as technologies become more complex, their implementation will also be more complex and require additional education and training.

FHWA

TRB Executive Director Robert E. Skinner, Jr. *(left)* and H. Norman Abramson, Chairman of Research and Technology Coordinating Committee *(right)*, present copy of committee's report, Highway Research: Current Programs and Future Directions, to FHWA Administrator Rodney Slater.

New Emphasis Areas

The following topics warrant increased emphasis and resources in the future highway R&T program.

- *Reassessment of the U.S. transportation system and the role of highways.* The question of what the highway transportation system should be like in 20 years—or 30 or 40 years—needs to be addressed and a strategic direction explored.
- *Environmental research.* Research is needed to better understand how highway transportation contributes to various local, national, and international environmental problems. More needs to be known about the costs, effectiveness, and other consequences of design changes, material choices, and system performance of transportation-related policy proposals aimed at reducing harm to the environment.

Research and Technology Coordinating Committee

H. Norman Abramson, Southwest Research Institute, San Antonio, Texas (retired), *Chairman*
A. Ray Chamberlain, American Trucking Associations, Alexandria, Virginia, *Vice Chairman*
Laurence J. Adams, Martin Marietta Corporation, Bethesda, Maryland (retired)
Kathleen Braaten, Richland County Commissioner, North Dakota (retired)
David G. Burwell, Rails-to-Trails Conservancy, Washington, D.C.
Raymond F. Decker, University Science Partners, Ann Arbor, Michigan
James N. Denn, Minnesota Department of Transportation, St. Paul
John W. Fisher, Lehigh University, Bethlehem, Pennsylvania
Delon Hampton, Delon Hampton and Associates, Washington, D.C.
Thomas F. Humphrey, Massachusetts Institute of Technology, Cambridge
Lester P. Lamm, Highway Users Federation for Safety and Mobility, Washington, D.C.
Charles A. Machemehl, Jr., Vulcan Materials Company, Birmingham, Alabama
Ray D. Pethtel, Virginia Polytechnic Institute and State University, Blacksburg
Stephen Edwin Rowe, S. E. Rowe and Associates, Hacienda Heights, California
Patricia F. Waller, University of Michigan, Ann Arbor
Richard P. Weaver, California Department of Transportation, Sacramento
Franklin E. White, Los Angeles County Metropolitan Transportation Authority, California
Clyde E. Woodle, Jr., Trucking Research Institute, Alexandria, Virginia
Charley V. Wootan, Texas Transportation Institute, College Station

Liaison Representatives
Robert J. Betsold, Federal Highway Administration, U.S. Department of Transportation
John A. Clements, Federal Highway Administration, U.S. Department of Transportation
Dennis C. Judycki, Federal Highway Administration, U.S. Department of Transportation
Francis B. Francois, American Association of State Highway and Transportation Officials, Washington, D.C.

• *Contracting for innovation.* More research is required to determine the extent that practices, put into place to reduce risk, protect public investments, and ensure accountability, impede innovation, and what alternatives or incentives are available to encourage innovation.

• *Support for breakthrough research.* Although some resources are being focused on breakthrough research, more could be done. In addition, if a portion of current defense conversion activities is directed to highway transportation problems, the range of potential breakthrough research topics could be broadened.

• *Overcoming barriers to long-term and intermodal research.* Many complex transportation topics that should be addressed are not because there is little support for long-term research or funding, or research that cuts across modal boundaries. Gaining support for research in these areas will require changes in research program funding and management.

Categories of R&T Activity

Category 1: Incremental Improvements in Highway Performance and Costs
Such research pursues evolutionary changes in the ways in which highways are planned, designed, constructed, maintained, financed, and managed; it seeks payoffs that are relatively certain and tangible: reduced maintenance and construction costs, added highway capacity, reduced highway fatalities and injuries, reduced adverse environmental impacts, and a variety of user benefits (improved travel time, fewer hazards, and so on).

Category 2: Breakthrough Research To Improve Highway Performance and Costs
This research is aimed at breakthroughs leading to dramatic improvements in highway performance and cost. Examples include new ways to control vehicles on highways through electronics, building bridges using newly engineered materials, and designing asphalt pavements with radically new approaches to modeling performance. This is speculative, high-risk research with potentially high payoffs.

Category 3: Reassessment of U.S. Transportation System and the Role of Highway Transportation
This research takes a long-term view of highway transportation and its interactions with other modes, land use, the environment, and the national economy; it seeks to better understand these interactions and to help shape the long-term direction of both urban and rural highway transportation in the United States as well as in regions and individual states.

Category 4: Compliance with Government Regulations and Policy Proposals
This category includes both research that examines proposals for changes (mostly short and midrange) in regulations, taxes, and other policies that affect highway transportation and research that helps highway agencies and others comply with new regulations and policies.

Category 5: Improvements in Intermodal Transportation Services that Involve Highways
Research in this category addresses interconnections between highways and other modes and ways in which these interconnections can be modified or developed to improve door-to-door intermodal transportation services. It includes physical design as well as the institutional, economic, administrative, and regulatory issues associated with developing better intermodal connections.

Category 6: Transfer of Promising Research Findings to Field Application
Activities in this category are aimed at transferring promising research results to field application and involve such mechanisms as demonstrations, publications, and special training activities as well as studies, surveys, and monitoring activities that seek to better understand and improve the effectiveness of the innovation process for highways.

Category 7: Education and Training of Highway Professionals
Although the activities in this category are not always considered part of the R&T program, they are essential to building the technology and knowledge bases necessary for innovation.

Category 8: Other Research, Technical Support, and Testing
This final category contains a broad range of investigatory, testing, certification, and support activities that do not fall into the previous seven categories.

Results of TRB Study

ENSURING RAILROAD TANK CAR SAFETY

About 115,000 railroad tank cars operating in the United States are used to ship bulk liquids and gases regulated by the U.S. Department of Transportation because their contents are flammable, corrosive, poisonous, or pose other hazards if accidentally released. These materials—including industrial acid, fertilizer, fuel, and alcohol—are essential to manufacturing, agriculture, and other sectors of the economy.

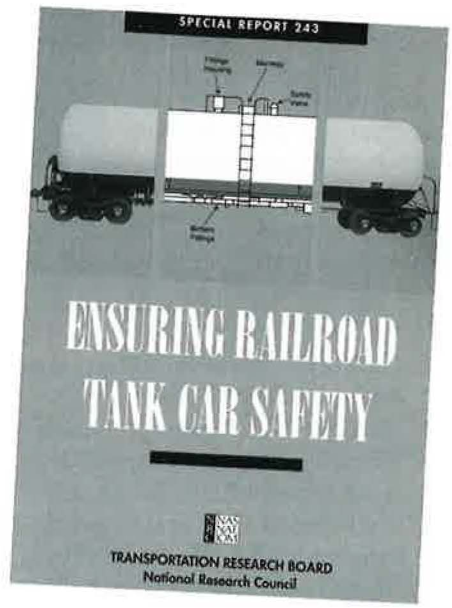
To ensure the safety of tank cars, DOT and industry have taken steps to enhance both the tank car and the environment in which it operates. These efforts have been highly successful. Each year tank cars make about 1 million trips carrying hazardous materials. Accidental releases occur approximately once out of every 1,000 shipments, resulting in about 1,000 releases each year. The majority of these releases are small spills and leaks that are the result of defective or poorly secured valves and other tank fittings. Fatal releases are especially rare. Since 1980 one person has died as a result of a tank car accident.

Tank cars have not always performed as well. From 1965 to 1980 more than 40 people were killed in tank car accidents. Many involved damage to pressure tank cars carrying flammable gases. Often the ends, or heads, of these tank cars were punctured by the couplers of adjoining cars during car switching operations or train derailments. These incidents sometimes resulted in massive fires that engulfed adjacent tank cars carrying flammable gases, setting off a chain reaction of fires and explosions. In several cases flammable gas cars heated by fire ruptured violently after firefighters and other emergency responders had arrived at the scene.

As a result of these incidents, puncture protection devices, consisting of steel plates placed in front of the tank heads, were required on flammable gas cars to shield the tank ends from impacts during derailments and other crashes. To prevent fire-induced tank ruptures, special heat-resistant tank insulation systems, known as thermal protection, were required on flammable gas cars. As an additional safeguard, special coupler-restraint systems, called double-shelf couplers, were installed on all tank cars carrying hazardous materials. These devices, which provide more secure interlocking of tank cars with adjoining cars, help prevent collisions during coupling and rollover damage during derailments.

Today about two-thirds of pressure tank cars—which account for about 40 percent of tank cars used in hazardous materials service—are equipped with head protection, and about half are equipped with thermal protection. All tank cars in hazardous materials service have double-shelf couplers. The advent of these safety devices helped bring about sharp declines in tank punctures, ruptures, and resultant fatalities. Punctures dropped by more than 90 percent after head protection systems and double-shelf couplers were installed on flammable gas cars starting in the late 1970s. Tank ruptures also declined dramatically after the installation of thermal protection. At the same time punctures and other types of accident damage declined among tank cars not equipped with head protection, because of the widespread use of double-shelf couplers and improvements in the railroad operating environment and tank car handling and loading practices.

Major classes of tank cars not equipped with head protection include nonpressure cars—which carry liquids and account for about 60 percent of tank cars in hazardous materials service—and pressure cars that carry nonflammable and nonpoisonous gases. The materials carried in these cars are generally less volatile and threatening than are the flammable and poison gases. Yet these tank cars and materials are sometimes involved in serious incidents. During the past 10 years several incidents involving nonpressure tank cars have resulted in injuries, community evacuations, environmental contamination, and other adverse consequences. These incidents led the National Transportation Safety Board and others to question some of the procedures used by government and industry in ensuring the safety of tank car designs and to call for head protection to be required on more types of tank cars.



TRB *Special Report 243: Ensuring Railroad Tank Car Safety* is available from the Transportation Research Board.

In the 1990 Hazardous Materials Transportation Uniform Safety Act, Congress called for an examination of the tank car design process and an assessment of whether head shields should be required on all tank cars carrying hazardous materials. To conduct the study, TRB convened a committee of experts in tank car design, chemical and mechanical engineering, transportation and hazardous materials safety, chemical shipping, railroad operations and labor, and transportation economics and regulation.

After reviewing tank car incident data, the committee concluded that trends in tank car safety are good and found no indication of safety problems emerging that might alter these trends. After examining the system for ensuring tank car safety, which consists of government and industry standard setting, research, and enforcement activities, the committee concluded that the system is fundamentally sound and comparable with those used for other vehicles and containers that require high levels of safety assurance. The committee concluded, however, that new safety demands—resulting from changes in public safety expectations, the environment in which tank cars operate, and the types of materials shipped in tank cars—warrant further improvements in procedures for ensuring tank car safety. The following measures were recommended:

- *Improve DOT and industry cooperation to identify critical safety needs and goals and take action to achieve them.* DOT and industry have vital roles in ensuring tank car safety. Each monitors tank car condition and safety performance in the field, investigates prospective safety improvements, and sets standards for tank car design, maintenance, and operations. The committee concluded that DOT and industry need to develop better relationships and procedures for preventing safety problems instead of reacting to them as they occur. Recommendations call for improving procedures for sharing information and expectations about long-term safety needs and goals and for planning and committing to specific actions to achieve them.

- *Improve the implementation of industry design approval and certification functions and federal oversight procedures.* Like many agencies responsible for the safety of transport vehicles and containers, DOT depends on industry to ensure broad compliance with design standards and good practices. In this regard, the Association of American Railroads' Tank Car Committee (TCC), which is composed of representatives of railroads, tank car suppliers, and shippers, is authorized to review and approve tank car design drawings; methods of construction and repair; and other aspects of tank car design, maintenance, and construction. Recommendations call for DOT to provide a clearer explanation of the TCC's approval authorities and government's oversight responsibilities and to work with industry to ensure that TCC is able to devote sufficient time and resources to those activities of greatest importance to safety.

- *Strengthen the information and criteria used in assessing the safety performance of tank car design types and assigning materials to tank cars.* DOT sets design criteria for the dozens of tank car design types. The hundreds of hazardous materials regulated by DOT are subject to restrictions on the type of tank car in which they can be transported. Correct assignment of hazardous materials to design types requires a thorough understanding of the safety performance of each design and the physical, chemical, and hazard characteristics of the materials shipped in tank cars. Recommendations call for DOT to develop more comprehensive information and criteria for evaluating the safety performance of individual tank car design types and the hazard characteristics of the many different kinds of hazardous materials.

In considering the need for head protection on all tank cars in hazardous materials service, the committee concluded that head protection is essential for tank cars carrying materials with the greatest potential to harm humans and the environment if released, but concluded that a requirement for head protection on all tank cars in hazardous materials service is not warranted by the information currently available. Because a small portion of tank car releases is caused by damage to tank car heads and because there is wide variation in the types of hazards posed by the materials shipped in tank cars, the committee concluded that further requirements for head protection must be carefully targeted. By developing better information on the safety performance of individual tank car design types and the hazard characteristics of the materials shipped in them, as recommended, the committee believes DOT will have a stronger technical basis for identifying those instances in which additional safety features such as head protection are warranted and for reassigning materials to safer tank car design types when necessary.

Committee for the Study of the Railroad Tank Car Design Process

Herbert H. Richardson, Texas A&M University System, College Station, *Chairman*
Robert G. Loewy, Georgia Institute of Technology, Atlanta, *Vice Chairman*
Edward J. Bentz, Jr., E. J. Bentz and Associates, Inc., Springfield, Virginia
Lawrence W. Bierlein, Swidler & Berlin Chartered, Washington, D.C.
George P. Binns, National Railway Passenger Corporation (Amtrak), Philadelphia, Pennsylvania
Leigh B. Boske, University of Texas, Austin
Thomas H. Dalrymple, Trinity Industries, Inc., Dallas, Texas
Lemoine V. Dickinson, Jr., Failure Analysis Associates, Inc., Alexandria, Virginia
Theodore S. Glickman, Resources for the Future, Washington, D.C.
Milton R. Johnson, IIT Research Institute, Chicago, Illinois
Henry B. Lewin, Transportation Communications International Union, Washington, D.C.
John P. Provinski, E. I. du Pont de Nemours and Co., Wilmington, Delaware
Phani K. Raj, Technology and Management Systems, Inc., Burlington, Massachusetts
Deborah K. Shaver, ICF Incorporated, Fairfax, Virginia
J. Reed Welker, University of Arkansas, Fayetteville

PROFILE

Thomas J. Pasko, Jr.

Federal Highway Administration

Thomas J. Pasko, Jr., Director of the Office of Advanced Research at the Federal Highway Administration since 1991, has served as a researcher and administrator for more than 30 years. His current position was created in response to the Intermodal Surface Transportation Efficiency Act of 1991, which dictated funds for long-range research projects.

After graduating from Pennsylvania State University, Pasko began his career with the then Pennsylvania Department of Highways. He obtained a master's degree from Penn State in 1961 and joined the Bureau of Public Roads (now FHWA). In 1967 he returned to school, where he served as an instructor at Cornell University while completing two years toward a Ph.D. degree. He joined FHWA as a highway research engineer and subsequently headed the Paving and Structural Materials Group, Materials Technology and Chemistry Division, and Pavements Division before becoming Director of the Office of Engineering and Highway Operations in 1987.

Under Pasko's direction, the Office of Advanced Research is currently working in seven broad areas: advanced materials, self-monitoring systems, robotics, analysis techniques using new computers, energy and conservation technologies, future freight movement techniques, and man-computer interfacing (such as virtual reality). The projects accomplished have included the initiation of a grant program for new technologies; the launching of the HITEC (Highway Innovative Technology Evaluation Center) program, operated by the Civil Engineering Research Foundation, to help deploy innovations; a series of workshops on merging robotics needs with products from the defense industry; and initiation of work in adapting advanced computer technology into the transportation area.

Over the years Pasko has worked on innovative projects including epoxy-coated rebars, internally sealed concrete, fiber-reinforced concrete, cathodic protection, Sulphlex (a substitute for asphalt), calcium magnesium acetate (an alternative deicer), and structural concepts such as self-stressed and prestressed pavements and autostress bridge design.

Pasko says he has seen many good technical solutions developed to satisfy highway needs with only a limited number of marketing successes. Unfortunately research organizations such as governmental agencies and universities are not always good at predicting which products will be successful.

"Our experience tells us that innovations are only adopted after the users are comfortable with the product, are confident that the product does what is expected, and that [it] is affordable," Pasko notes. "We in the highway construction community have had limited success in pushing innovations from the top downward through the states to the potential users because of the vast amounts of education and hand-holding that are needed."

Through various subcommittees of the National Science and Technology Council, Pasko is currently involved in programs to improve the nation's infrastructure. In particular he cites an industry/government interagency initiative to use improved, high-performance materials. The initial effort is concerned with the use of higher-strength portland cement concretes, an outgrowth of projects conducted by the Strategic Highway Research Program.

As a practical example, Pasko points out that most agencies are designing bridges for less than 42 MPa (6,000 pounds per square inch) concrete [by comparison, the ultimate strength of concrete in the laboratory is 750 MPa (107,000 psi)]. Several bridges have been built using high-strength materials and have shown savings. When 70 MPa (10,000 psi) concrete is used, about one third of the volume of the concrete can be saved, fewer girders are needed, and longer spans are possible.

Through Pasko's office, a multi-year research and development program has

continued on page 37

PROFILE

Chris Hendrickson

Carnegie-Mellon University

How can transportation professionals best harness revolutionary changes? This question is a continuing focus of research for Chris Hendrickson, Professor of Civil Engineering and Associate Dean of Engineering at Carnegie-Mellon University.

"Transportation evolves both by a series of incremental improvements and by relatively sudden shifts that reveal new opportunities or problems," Hendrickson says. "It is these revolutionary changes that most interest me." He cites as one current example the opportunity available from rapid improvements in computing capabilities. Another is "the looming specter of finite limits on the supply of petroleum. Whether or not we believe that alternative power sources will be available for transportation as petroleum supplies dwindle is a fundamental question for any transportation professional." He also mentions organizational changes, which "can also be revolutionary in nature, such as the switch to public ownership of intercity roadways [during the] last century."

After earning B.S. and M.S. degrees in engineering from Stanford University, Hendrickson spent two years at Oxford University as a Rhodes Scholar, completing an M.Phil. degree in economics in 1975. He received a Ph.D. in civil engineering from the Massachusetts Institute of Technology in 1978.

Following his experience with a municipal city planning department, the U.S. Environmental Protection Agency, and the Volpe Transportation Center, Hendrickson joined the faculty of Carnegie-Mellon University. He has held a faculty appointment in civil and environmental engineering since 1978, but also has administrative appointments as Associate Dean of the Engineering College and Education Director of the National Science Foundation's Engineering Design Research Center at the university.

Active on TRB committees for a number of years, Hendrickson has chaired the Committee on Applications of Emerging Technology since 1988. "The charge to this committee is to seek out new and emerging technology relevant to transportation applications. We explore everything from new sensor instrumentation [to] construction robotics and biotechnology applications. For example our 1995 TRB Annual Meeting sessions focus on multimedia computer applications and defense conversion opportunities." He has also served on the committees on Application of Emerging Technology, Transportation Supply Analysis, and Taxation and Finance. He is currently a member of the Committee on Artificial Intelligence. From 1982–1988 he was Carnegie Mellon University's TRB representative.

At present Hendrickson is working in two research areas. First, he is continuing with efforts intended to exploit new computing technology. "With computing power [becoming] increasingly inexpensive, it makes sense to employ numerous approaches and algorithms for tasks such as scheduling or monitoring." He gives as an example exploratory work he is undertaking with colleagues on using multiple algorithms simultaneously for roadway incident detection. Similarly, he notes, new generations of field computers should be easier to program and maintain while being capable of doing multiple tasks in parallel. Computers used for signal control might also monitor sewers, air pollution, and the weather, services that could be revenue producers for transport agencies. "When we demonstrated a new generation traffic controller software in Sacramento, California," he reports, "we replaced a refrigerator-sized minicomputer with a small box."

His second area of research involves the development of "green design" methods to make products and processes more environmentally benign. "Sustainable development is a basic social goal, and engineers and transportation professionals need to contribute. We are exploring new methods for life-cycle assessment to abstract the environmental and economic implications

continued on page 37

TRB HIGHLIGHTS

Cooperative Research Programs News

Transit Cooperative Research Program

Impact of Radio Frequency Refarming on Transit Communications

The Federal Communications Commission has decided to use "refarming" to help mitigate radio frequency congestion and increase spectrum efficiency in the private land mobile radio bands (frequencies below 512 megahertz). Refarming is the reduction in bandwidth allocated to radio channels in the designated bands. Base stations and mobile radios operating within these bands will be obsolete if they are unable to operate in the reduced bandwidth. The refarming of frequencies is likely to have a significant impact on transit communications systems and capital procurement of communications equipment in the future.

Arthur D. Little, Inc., has been awarded a one-year $119,728 contract (TCRP Project C-5, fiscal year 1994) to define the scope of the planned FCC changes as they relate to the transit industry and to characterize and assess the impacts on the industry.

For further information, contact Christopher Jenks, TRB (telephone 202-334-3502).

Tools for Transit Risk-Exposure Identification and Treatment for Bus Systems

Identification of risk exposure is the cornerstone of the risk-management process because the other elements of risk management rest on the accuracy and completeness of this process. Public bus transit systems have not developed a uniform or systematic methodology to analyze property and casualty exposures, and the effectiveness of the approaches currently used is unknown. For bus transit systems with limited resources and risk-management expertise, a user-friendly methodology for identifying and priority ranking risk exposures is essential to control potential loss.

The Risk Management Center, Inc., has been awarded an 18-month, $194,964 contract (TCRP Project G-3, fiscal year 1994) to (*a*) design tools with which bus transit and paratransit systems can identify exposures to loss, assess risk within their systems, evaluate their loss-control programs against best practices, and make informed decisions about financing risk and (*b*) develop guidelines to collect, categorize, and disseminate loss data that are consistent and compatible among systems.

For further information, contact Christopher Jenks, TRB (telephone 202-334-3502).

Rail-Corrugation Mitigation in Transit

Rail corrugation is a serious and costly problem for many rail transit agencies. Research is needed to provide a better understanding of the rail-corrugation initiation and growth process; to establish the influence of track, vehicle, and operating characteristics on rail-corrugation development; and to develop suitable means for reducing rail corrugation. This research will yield economic advantages through the reduction of maintenance needs and provide other economic and environmental benefits.

The Association of American Railroads has been awarded an 18-month, $499,691 contract (TCRP Project D-1, fiscal year 1993) to (*a*) develop methods to reduce or eliminate rail corrugation through the identification and use or adoption of compatible vehicle and track components and (*b*) provide guidelines that can be used by transit agencies to reduce or eliminate rail-corrugation occurrences.

For further information, contact Amir Hanna, TRB (telephone 202-334-1892).

30-Year Anniversary

James Scott, Transportation Planner, recently marked his 30-year anniversary with the Transportation Research Board.

Robotics in North Carolina
continued from page 16

References

1. *National Crane Owner's Manual for the Series 400A,* Waverly, Neb., 1989.

2. Paulson, B. C., and H. Sotoodeh-Khoo. Teaching Experiment in Real-Time Construction Data Acquisition. *Earth Moving and Heavy Equipment,* American Society of Civil Engineers, New York, N.Y., 1986, pp. 182–194.

3. Kapsanis, K. A. OSHA's New Rule on Lead: Changing the Practice and Price of Lead Paint Removal. *Journal of Protective Coatings and Linings,* July 1993, pp. 46–51.

4. Cignatta, J.V. Use of Robotics for Replacing Blasters at Industrial Painting Projects. In *Proc., Steel Structures Painting Council,* New Orleans, La., 1993, pp. 74–103.

5. Sturdivant, V., and R. Veniger. Robots Take Off in Aircraft Paint Stripping. *Robotics Today,* Society of Manufacturing Engineering, 3(3), 1990, pp. 1–4.

6. Innovative Practice. *Journal of Protective Coatings and Linings,* Oct. 10, 1993, pp. 48–50.

CALENDAR

TRB Conferences

1995

MARCH

6,7 Forum on Future Directions in Transportation Research and Development
Washington, D.C.
Robert E. Spicher, TRB

9–12 Workshop on Disadvantaged Business Enterprises
Baltimore, Maryland
Frederick D. Hejl, TRB

13–15 New Concepts in Household Travel Surveys
Irvine, California
James A. Scott, TRB

20, 21 International Conference on Global Transportation Information Sources, Systems, and Services
Washington, D.C.
Barbara Post, TRB

APRIL

2–7 3rd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
St. Louis, Missouri
Shamsher Prakash (314-341-4489)

17–21 5th International Conference on Transportation Planning Methods and Applications
Seattle, Washington
James A. Scott, TRB

MAY

8–10 2nd Symposium on Integrated Traffic Management Systems
Seattle, Washington
Richard A. Cunard, TRB

14–17 Symposium on Visualization, Simulation, and Transportation
Houston, Texas
Richard F. Pain, TRB

19–21 Workshop on Reforming Highway Maintenance Using Total Quality Management
Whitefish, Montana
Frank Lisle, TRB

21–24 Conference on the Role of Metropolitan Planning Organizations in Transportation
Williamsburg, Virginia
James A. Scott, TRB

JUNE

25–29 6th International Conference on Low-Volume Roads
Minneapolis, Minnesota
G. P. Jayaprakash, TRB

JULY

11–13 TRB Joint Summer Meeting of the Planning, Economics, Finance, and Management Committees
Lake Placid, New York
Kenneth E. Cook and James A. Scott, TRB

16–20 7th International Conference on Mobility and Transport for Elderly and Disabled People
United Kingdom
James A. Scott, TRB

19–22 34th Annual Workshop on Transportation Law
Saratoga Springs, New York
James B. McDaniel, TRB

20, 21 20th Annual Summer Ports Conference
Boston, Massachusatts
Christina Casgar, TRB

27–29 Workshop on Public Transit Organization and Management
Irvine, California
Peter L. Shaw, TRB

AUGUST

23–25 Workshop on Extending the Life Span of Structures
San Francisco, California
Bill Dearasaugh, TRB

28–30 4th International Bridge Engineering Conference
San Francisco, California
Bill Dearasaugh, TRB

30–Sept 1 International Symposium on Highway Geometric Design Practices
Boston, Massachusetts
Richard A. Cunard, TRB

SEPTEMBER

22–24 SHRP and Traffic Safety on Two Continents
Prague, Czech Republic
Richard F. Pain, TRB

FALL

National Conference on Transportation Programming Methods and Issues
Irvine, California
James A. Scott, TRB

OCTOBER

10 Workshop on Wood Tie Use and Treatment Alternatives
Haines City, Florida
Elaine King, TRB

22–25 12th National Conference on Rural Public and Intercity Bus Transportation
Des Moines, Iowa
Peter L. Shaw, TRB

NOVEMBER

11–16 7th National Conference on Light Rail Transit
Baltimore, Maryland
Peter L. Shaw, TRB

TRB is either conducting or otherwise participating in the meetings listed above. For further information contact the person cited in each listing (telephone 202-334-2934). For program and registration information, contact Angelia Summons, Conference Manager (telephone 202-334-2934).

1995 TRB Committee Meetings

APRIL

23–25 General Asphalt Problems (A2D05)
Milwaukee, Wisconsin
Frederick D. Hejl (202-334-2952)

MAY

15–17 3D Visualization Conference and Mid-Year Meetings
Geometric Design (A2A02)
Simulation and Measurement of Vehicle and Operator Performance (A3B06)
User Information Systems (A3B08)
Houston, Texas
Richard F. Pain (202-334-2960)

JULY

11–13 Joint Meeting of the Planning, Economics, Finance, and Management Committees:
Taxation and Finance (A1A01)
Intergovernmental Relations and Policy Processes (A1A03)
Transportation and Economic Development (A1A06)
Strategic Management (A1A07)
Transportation Economics (A1C01)
Social and Economic Factors of Transportation (A1C06)
Statewide Multimodal Transportation Planning (A1D01)
Transportation and Land Development (A1D02)
Citizen Participation in Transportation (A1D04)
Transportation Planning Needs and Requirements of Small and Medium-Sized Communities (A1D05)
Transportation Programming, Planning, and Systems Evaluation (A1D06)
Lake Placid, New York
James A. Scott (202-334-2965) and Kenneth E. Cook (202-334-2966)

19–21 Inland Water Transportation (A1B01)
Intermodal Freight Transport (A1B05)
Ports and Waterways (A1B08)
Intermodal Freight Terminal Design and Operations (A2M03)
International Trade and Transportation (A5006)
Boston, Massachusetts
Christina Casgar (202-334-3205)

19–22 Eminent Domain and Land Use (A4001)
Tort Liability and Risk Management (A4002)
Emerging Technology Law (A4003)
Transportation Law (A4004)
Contract Law (A4005)
Environmental Issues in Transportation Law (A4006)
Transit and Intermodal Transportation Law (A4007)
Saratoga Springs, New York
James B. McDaniel (202-334-3205)

Other Meetings

3rd National Concrete and Masonry Engineering Conference
June 15–17, 1995
San Francisco, California
Sponsors Various concrete organizations
Subjects Cast-in-place, precast/prestressed, tilt-up, post-tensioned concrete, and clay and concrete masonry structures, including design of new multi-story buildings, practitioners guide to materials for concrete and masonry structures, design and repair of concrete parking structures, design of new concrete bridges, and retrofit of existing concrete bridges.
Contact NCMEC, 5420 Old Orchard Road, Skokie, Illinois 60077-1083 (telephone 708-966-6200, fax 708-966-9781).

13th International Conference on Alcohol, Drugs, and Traffic Safety
August 13–18, 1995
Adelaide, South Australia
Sponsors Federal Office of Road Safety, South Australian Department of Road Transport, and the University of Adelaide
Subjects Epidemiology, measurement and screening, driving performance, prevention, and rehabilitation programs.
Contact SAPMEA Conventions, 80 Brougham Place, North Adelaide, SA 5006, Australia (telephone 618 239 1515, fax 618 239 1566).

20th World Road Congress
September 3–9, 1995
Montreal, Canada
Sponsors Permanent International Association of Road Congresses
Subjects Performance management of road administrations, transportation and urban space planning, achieving quality in roadworks, and new techniques for pavement strengthening and maintenance.
Contact XXth World Road Congress, 1200 McGill College Avenue, Suite 1620, Montréal, Québec, Canada H3H 4G7 (telephone 514-864-1010, fax 514-873-1995).

Dynamic Behavior of Concrete Structures
September 5–8, 1995
Kosice, Slovakia
Sponsor RILEM (International Union of Testing and Research Laboratories for Materials and Structures) in collaboration with IABSE Slovak National Committee (International Association for Bridge and Structure Engineering), Technical University of Kosice, and EXPERTCENTRUM BRATISLAVA
Subjects New experimental testing methods, modal analysis of structures, dynamic testing of bridges, and earthquake influences on concrete structures.
Contact Tibor Javor, EXPERTCENTRUM, Sulekova 8, 811 06 Bratislava, Slovakia (telephone and fax 00-42-7-311 738).

1995 TAC Annual Conference
October 22–25, 1995
Victoria, British Columbia, Canada
Sponsor The Transportation Association of Canada
Subjects Conference theme: Transportation—Total Customer Satisfaction.
Contact Ariff Kachra, Member Services Manager, Transportation Association of Canada (TAC), 2323 St. Laurent Boulevard, Ottawa, Ontario K1G 4K6, Canada (telephone 613-736-1350, fax 613-736-1395).

1995 ASCE Transportation Congress
October 22–26, 1995
San Diego, California
Sponsor American Society of Civil Engineers, Management Group C: Air Transport, Highway, Urban Planning and Development, and Urban Transportation divisions
Subjects Public transport and transit systems, intermodal access and planning, high-speed and intercity rail services, environmental planning assessment and project development, congestion management, airport terminal planning and design, and others.

Contact B. Kent Lall, Chair, ASCE 1995 Transportation Congress, Portland State University, Department of Civil Engineering, P.O. Box 751, Portland, Oregon 97207-0751 (telephone 503-725-4245, fax 503-725-4298); or Walter T. Marlowe, Manager, Technical Services, ASCE, 1015 15th Street, N.W., Suite 600, Washington, D.C. 20005 (telephone 202-789-2200, fax 202-789-1298).

International Conference on Magnetically Levitated Systems
November 27–29, 1995
Bremen, Germany
Subjects Principles of magnetic levitation; suspension components with electromagnets, permanent magnets, and superconductors; guideway technology; linear motor propulsion; superconductor technology; and telecommunication and guidance system.
Contact Herbert Weh, c/o Technische Universität Braunschweig, Institut für Elektrische Maschinen, Antriebe und Bahnen, Hans-Sommer-Strasse 68, D-38106 Braunschweig, Germany.

CODATU VII
February 12–16, 1996
New Delhi, India
Sponsor Conference on Development and Planning of the Urban Transport (CODATU Association)
Subjects Transport and city shape, economic costs of large transport projects, financing urban transport investments, transport systems hierarchies and coverage, innovative legal and institutional frameworks for urban transport, and dealing with transport externalities.
Contact Association CODATU, 22 rue d'Alsace, 92300 Levallois-Perret, France.

PROFILE

Pasko *continued from page 32*

been arranged with a user agency, the Texas Department of Transportation, to design and build higher-strength bridges. The first bridge is under construction with 100 MPa (13,000 psi) concrete. The information gained from this type of project is being passed on to other user agencies through the efforts of FHWA's Office of Technology Applications. Simultaneous efforts are under way to overcome the various barriers to raising the levels of technology used. Similar technological advancement programs, built around the users, are also being developed by Pasko's office for bridge instrumentation and monitoring systems and robotics.

"A major point to be made is that creating an innovation is relatively easy," Pasko says. "The difficulty is [in] helping people become comfortable and confident with the innovation so that they become repeat users."

Committee work for professional organizations is an area of considerable interest to Pasko. He has served as a member of the Transportation Research Board's Group 2 Council and as Chair of Section E—Concrete. A former member of the Committee on Rigid Pavement Design and on Sealants and Fillers for Joints and Cracks, he currently serves on the National Cooperative Highway Research Program Project Panel on NCHRP—IDEA Innovations Deserving Exploratory Analysis.

Pasko is a member of about 15 technical organizations. In 1975 he was designated a Fellow of the American Concrete Institute and in 1989 a Fellow of the American Society of Civil Engineers. ACI honored him with its Kennedy Award in 1989 and in 1991 he was named Federal Engineer of the Year by the National Society for Professional Engineers/FHWA. Pasko, who was cited by *Engineering News Record* in 1971 for his work with prestressed pavements, is the author or coauthor of some 20 articles in journals and publications in his field.

PROFILE

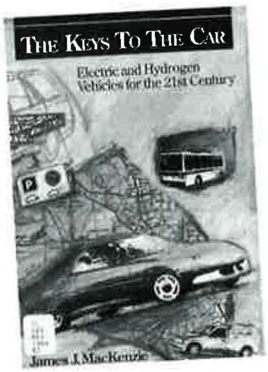
Hendrickson *continued from page 33*

of different decisions. Effective life-cycle assessment methods are desperately needed, but the current approaches are badly flawed." One topical application on which he and others are working is the assessment of processes for recycling batteries from electric vehicles.

Hendrickson has been recognized with a number of honors during his career, including the C. E. Ladd Research Award in 1979 and the Benjamin Richard Teare Teaching Award in 1987, both from Carnegie-Mellon University. He also received the Walter L. Huber Civil Engineering Research Prize in 1989 and the Frank M. Masters Transportation Engineering Award in 1994, both from the American Society of Civil Engineers.

The author of more than 100 professional papers, Hendrickson has coauthored four books, including a textbook, *Project Management for Construction* (with T. Au), which is in widespread use. In 1992 his paper, "Advanced Software Design and Standards for Traffic Signal Control," (coauthored with Darcy Bullock) was voted the Outstanding Paper of the Year in the 1992 ASCE *Transportation Engineering Journal.*

BOOKSHELF



The Keys to the Car: Electric and Hydrogen Vehicles for the 21st Century
World Resources Institute, P.O. Box 4852, Hampden Station, Baltimore, Md. 21211; 1994, softcover, $14.95, 128 pp.

A survey of the environmental and economic costs and benefits of alternative fuels and an examination of the status of electric vehicle research and technology.

The Measure of Man and Woman
Alvin R. Tilley. Whitney Library of Design, Watson-Guptill Publications, BPI Communications, Inc., 1515 Broadway, New York, N.Y. 10036. 1993, $60.00, 96 pp.

Recent data on the anthropometry and other characteristics of men, women, and children are given. Of particular interest to the transportation community are sections on maintenance access, safety at work and home, vehicular accommodation, displays, and the environment. The publication is the culmination of years of collection and synthesis of data needed in human engineering/ergonomics and for any design endeavor in which humans are part of the system.
—*Richard F. Pain*

Driving Future Vehicles
Andrew M. Parkes and Stig Franzén, eds. Taylor and Francis, 1900 Frost Road, Suite 101, Bristol, Pa. 19007 (telephone 800-821-8312; fax 215-785-5515); 1993, hardcover, $85.00, 458 pp.

A collection of some of the interesting and available material from the DRIVE and PROMETHEUS programs. Focus is on the act of driving the vehicle of the future; sections address road user needs, problems in vehicle systems, driver-oriented design, and methods in design and evaluation.

Progress in Cement and Concrete, Volume 4: Mineral Admixtures in Cement and Concrete
Shondeep L. Sarkar and S. N. Ghosh, eds. ABI Books Pvt. Ltd., 404 Skipper Corner, 88 Nehru Place, New Delhi 110 019, India (telephone 91-11-643-2653; fax 91-11-644-8917); 1993, hardcover, 565 pp.

Current trend in concrete technology, which is toward the use of admixtures, is addressed by scientists and technologists in areas such as hydration, durability, and other physical and mechanical properties.

Going Private: The International Experience with Transport Privatization
José A. Goméz-Ibáñez and John R. Meyer. Brookings Institution, 1775 Massachusetts Avenue, N.W., Washington, D.C. 20036 (telephone 202-797-6258); 1993, hardcover $36.95, softcover $16.95, 310 pp.

The experiences of governments in privatizing transport are examined; cases are drawn from the United States, Asia, Europe, and Latin America. The authors focus on highway and bus privatization, although urban rail transit and airports are also considered. Concerns include cost and financing as well as siting, equity, income transfers, pricing, and government regulation.

CTA at 45
George Krambles and Arthur H. Peterson. George Krambles Transit Scholarship Fund, P.O. Box 345, Oak Park, Ill. 60303; 1993, hardcover, $49.95, 144 pp.

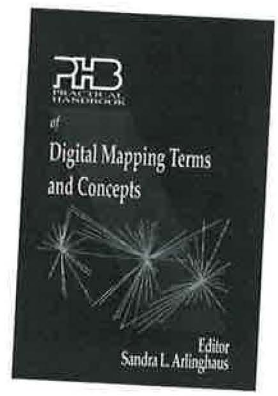
The account of the first 45 years of the Chicago Transit Authority, North America's second largest public transit system, traces the experiences of a major American city in adapting its public transportation system from a private monopoly to part of the national urban transportation system.

Significance of Tests and Properties of Concrete and Concrete-Making Materials (STP 169C)
Paul Klieger and Joseph F. Lamond, eds. American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103 (telephone 215-299-5585; fax 215-977-9679); 1994, hardcover, $110.00, 630 pp.

The latest technology in concrete and concrete-making materials is presented. This revision to ASTM STP 169B contains 10 new chapters; all the other chapters have been revised or updated. The six parts address product quality, freshly mixed concrete, hardened concrete, concrete aggregates, other concrete-making materials, and specialized concretes.

Community/Corridor Traffic Safety Programs
Center for Urban Transportation Research, College of Engineering, University of South Florida, 4202 East Fowler Avenue, ENB 118, Tampa, Fla. 33620; 1994, softcover, 64 pp.

This guide was developed for city, community, and county people and organizations interested in forming a traffic safety program. Problem identification, goal setting, organization, and resources are discussed, and case studies are included.



Practical Handbook of Digital Mapping: Terms and Concepts
CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431-9868 (telephone 800-272-7737, fax 800-374-3401); 1992, ISBN 0-8493-0131-9, $59.95 (outside U.S. $72.00), 335 pp.

Practical introduction to digital mapping, with an explanation of its original application in the international development community. Includes appendixes covering railroad terminology, desktop digital mapping, maps on CD-ROM, intelligent transportation systems, and tools used in the global positioning system.

Causes and Deterrents of Transportation Accidents: An Analysis by Mode
Peter D. Loeb, Wayne K. Talley, and Thomas J. Zlatoper. Quorum Books, Greenwood Publishing Group, Inc., 88 Post Road West, P.O. Box 5007, Westport, Connecticut 06881-5007 (telephone 203-226-3571, fax 203-222-1502); 1994, $59.95, 240 pp.

Causes and deterrents of transportation accidents are examined by mode, with the focus on accidents in the United States. The survey results enhance understanding for developing effective multimodal public policies for improving transportation safety. Of interest to policy makers and investigators of transportation safety.

Transit System Security: Program Planning Guide
U.S. Department of Transportation, 400 7th Street, S.W., Washington, D.C. 20590; 1994, DOT-VNTSC-FTA-94-1, $27.00, 130 pp.

A discussion of the development of a transit system security plan and program. Described are the key elements to be included, such as policy and management commitments, elements of the transit system, management of the program, definition of roles and responsibilities, threat and vulnerability assessment, and plan evolution.

NOTE: The publications described above are not available through TRB but can be ordered directly from the publishers, which are noted in each listing.

New TRB Publications

Innovations in Instrumentation and Data Acquisition Systems
Transportation Research Record 1432
The roles of laboratory testing, field monitoring, development of sensors, training, and centrifuge testing in transportation are addressed.

1994, 105 pp., TRB affiliates, $18.75; nonaffiliates, $25.00. Subscriber category: soils, geology, and foundations (IIIA).

Public Transportation: Bus, Rail, Ridesharing, Paratransit Services, and Transit Security
Transportation Research Record 1433
New research in the operational and service delivery aspects of public transportation is reviewed. New ideas are explored and improved tactics in each category are discussed.

1994, 211 pp., TRB affiliates, $32.25; nonaffiliates, $43.00. Subscriber category: public transit (VI).

Subsurface Drainage, Soil-Fluid Interface Phenomena, and Management of Unpaved Surfaces
Transportation Research Record 1434
Issues related to subsurface drainage of slopes, embankments, and pavement subgrades; phenomena at the soil-fluid interface; and management systems for unpaved and aggregate-surfaced roads are presented.

1994, 96 pp., TRB affiliates, $19.00; nonaffiliates $25.00. Subscriber categories: pavement design, management, and performance (IIB); soils, geology, and foundations (IIIA).

Pavement and Traffic Monitoring and Evaluation
Transportation Research Record 1435
The focus of most of the papers is current information on pavement and traffic monitoring and evaluation. Metric conversion is also discussed.

1994, 187 pp., TRB affiliates, $26.25; nonaffiliates, $35.00. Subscriber category: pavement design, management, and performance (IIB).

Asphalt Concrete Mix Materials
Transportation Research Record 1436
Of interest to state and local construction, design, materials, and research engineers as well as contractors and material producers, the topics are relationship between asphalt physical and chemical properties and field performance; recent developments in asphalt binders; experiences with crumb rubber in asphalt mixes; and liquid antistrip additives, natural sands, and olive husks in asphalt mixes.

1944, 132 pp., TRB affiliates, $21.75; nonaffiliates, $29.00. Subscriber category: materials and construction (IIIB).

Aggregates: Waste and Recycled Materials; New Rapid Evaluation Technology
Transportation Research Record 1437
Provided in the first group of papers are the results of research related to waste and recycled materials. In the second group the development and use of aggregate tests based on new technologies are described.

1994, 64 pp., TRB affiliates, $15.75; nonaffiliates, $21.00. Subscriber categories: soils, geology, and foundations (IIIA); materials and construction (IIIB).

Research Issues on Bicycling, Pedestrians, and Older Drivers
Transportation Research Record 1438
Of interest to highway and traffic planners, designers, and operators, three areas—bicycling and bicycle facilities, pedestrians and pedestrian facilities, and older driver training and performance—are addressed.

1994, 98 pp., TRB affiliates, $18.75; nonaffiliates, $25.00. Subscriber category: safety and human performance (IVB).

Durability of Geosynthetics
Transportation Research Record 1439
Information is presented on the durability of geosynthetics used in various applications and methods used for testing. Various sources are provided that could affect the properties of these materials.

1994, 54 pp., TRB affiliates, $12.75; nonaffiliates, $17.00. Subscriber category: soils, geology, and foundations (IIIA).

Design and Performance of Stabilized Bases, and Lime and Fly Ash Stabilization
Transportation Research Record 1440
Design and performance of stabilized bases, and lime and fly ash stabilization of soils are covered, with information based on both laboratory and field investigations.

1994, 78 pp., TRB affiliates, $18.00; nonaffiliates, $24.00. Subscriber category: soils, geology, and foundations (IIIA).

Nonmotorized Transportation Around the World
Transportation Research Record 1441
Papers are presented in four topical groupings: aspects of transportation in the People's Republic of China, the cost and consequences of mobility, nonmotorized transportation in Asia and Africa, and nonmotorized transportation issues and experiences in developing countries.

1994, 150 pp., TRB affiliates $24.75; nonaffiliates $33.00. Subscriber categories: safety and human performance (IVB); planning, administration, and environment (I).

Maintenance of the Highway Infrastructure
Transportation Research Record 1442
Highway maintenance management, safety, structures, and snow and ice control are addressed.

1994, 169 pp., TRB affiliates $26.25; nonaffiliates $35.00. Subscriber category: maintenance (IIIC).

Travel Demand Modeling and Network Assignment Models
Transportation Research Board 1443
Contains papers focusing on forecasting modeling techniques, traffic assignment methods under various conditions, trip chaining, and a network improvement model for programming network improvements.

1994, 118 pp., TRB affiliates $20.00; nonaffiliates $26.00. Subscriber category: planning and administration (IA).

Publications Order Form

Please send the following:

Qty	Title	Price: Nonaffiliates	Price: Affiliates
____	1995 Publications Catalog (CAT94)	No charge	No charge
____	TR News: __ Annual Subscription	$47.00[a]	No charge[b]
	__ Single Copy:	8.50	6.50
	(TRN __)		
____	TRB Directory (DR93)	35.00	26.25
	Bridge Aesthetics Around the World		
____	Hard cover (BAATHC)	85.00[c]	63.75[c]
____	Soft cover (BAATSC)	65.00[c]	48.75[c]
	Special Reports		
____	243 Railroad Tank Car Safety (SR243)	24.00	18.00
____	244 Highway Research (SR244)	17.00	12.75
	Transportation Research Records		
____	1432 Instrumentation (R1432)	25.00	18.75
____	1433 Public Transportation (R1433)	43.00	32.25
____	1434 Subsurface Drainage (R1434)	25.00	19.00
____	1435 Pavement and Traffic Monitoring (R1435)	35.00	26.25
____	1436 Asphalt Concrete Mix (R1436)	29.00	21.75
____	1437 Aggregates (R1437)	21.00	15.75
____	1438 Bicycling, Pedestrians, and Older Drivers (R1438)	25.00	18.75
____	1439 Durability of Geosynthetics (R1439)	17.00	12.75
____	1440 Stabilized Bases, Lime and Fly Ash Stabilization (R1440)	24.00	18.00
____	1441 Nonmotorized Transportation (R1441)	33.00	24.75
____	1442 Maintenance of Highway Infrastructure (R1442)	35.00	26.25
____	1443 Travel Demand Modeling (R1443)	26.00	20.00
	NCHRP Research Results Digests		
____	187 Wheel Loads (HRD187)	6.00	4.50
____	Highway Research Abstracts annual subscription (4 issues)	105.00[d]	105.00[d]
____	Transit Research Abstracts (1 issue)	82.00[e]	82.00[e]

For surface delivery outside North America, add $3.50 for first item and $1.00 for each additional item, except as noted.

[a]$58.00 overseas.

[b]One subscription included in affiliate fee; additional subscriptions, $35.00.

[c]For overseas orders, add $4.50 per book for surface mail and $22.00 per book for air mail.

[d]$121.00 overseas.

[e]$89.00 overseas.

Payment must accompany orders. Foreign payments must be in U.S. funds drawn on a U.S. bank or by international money order (payer must bear all bank charges). Return this form with payment to Transportation Research Board, Box 289, Washington, D.C. 20055.

__ Please send information on TRB affiliates program
__ Check or money order enclosed
__ Charge ($10.00 minimum) to:
Visa __ MasterCard __ American Express __

Payments for deliveries to Calif., D.C., Fla., Md., Mo., Tex., and Canada must include applicable sales tax/GST.

Card Number

____/____/____/____

Expiration Date (Mo) (Yr)

__/__

Signature ____________________

Date ____________________

Affiliate No. ____________________

Name ____________________

Agency ____________________

Street ____________________

City ____________________

State ____________________ Zip ______

Telephone (____) ____________________

TRN

Information for Contributors to *TR News*

TR News welcomes the submission of manuscripts for possible publication in the categories listed below. All manuscripts submitted are subject to review by the Editorial Board and other reviewers to determine suitability for *TR News*; authors will be advised of acceptance of articles with or without revision. All manuscripts accepted for publication are subject to editing for conciseness and appropriate language and style. Proofs of edited manuscripts will be provided for author review only on request.

FEATURES are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 to 4,000 words (12 to 16 double-spaced, typewritten pages), and accompanied by appropriate and professionally drawn line drawings, charts, or tables, and glossy, black-and-white, high-quality photographs (with corresponding captions). Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

RESEARCH PAYS OFF highlights research that provides useful, cost-effective solutions to important transportation-related problems in all modes, whether they pertain to improved transport of people and goods or provision of better facilities and equipment permitting such transport. Articles should describe cases in which the application of research findings resulted in substantial benefits to transportation agencies or to the public, or in which the payoff may be potential rather than actual. Articles (approximately 500 to 750 words) should delineate the problem, solution, application, and benefits, and be accompanied by an appropriate illustration and a logo that identifies the sponsor or research agency.

NEWS BRIEFS are short (100 to 750 words) items of interest and usually are not attributed to an author. They may be either text or photographic or a combination of both. Line drawings, charts, or tables may be used where appropriate. Articles may be related to construction, administration, planning, design, operations, maintenance, research, legal matters, or applications of special interest. Articles involving brand names or names of manufacturers may be determined to be inappropriate; however, no endorsement by TRB is implied when such information is used. Foreign news articles should describe projects or methods that have universal rather than local application.

POINT OF VIEW is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality illustrations, and are subject to review and editing. Readers are also invited to submit comments on published points of view.

CALENDAR covers (a) TRB-sponsored conferences, workshops, and symposia, and (b) functions sponsored by other agencies of interest to readers. Because of the lead time required for publication and the 2-month interval between issues, notices of meetings should be submitted at least 4 to 6 months before the event.

BOOKSHELF announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, and price. Publishers are invited to submit copies of new publications for review, and, on occasion, guest reviews or discussions will be invited.

LETTERS provide readers with the opportunity to comment on the information and views expressed in published articles, TRB activities, or transportation matters in general. All letters must be signed and contain constructive comments.

SUBMISSION OF ARTICLES Manuscripts submitted for possible publication in *TR News* and any correspondence on editorial matters should be directed to the Director of Reports and Editorial Services, Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418; telephone (202) 334-2972. All manuscripts must be submitted in duplicate, typed double-spaced on one side of the page and accompanied by word-processed diskette, and are subject to editing for conciseness and appropriate language and style. Required style for units of measurement: The International System of Units (SI), an updated version of the metric system, should be used as the primary units of measurement. In the text, the SI units should be followed, when appropriate, by the U.S. Customary equivalent units in parentheses. For figures and tables, use only the SI units, providing the base unit conversions in a footnote. Galley proofs for review by author will be furnished and original artwork returned only on request. Authors are responsible for the authenticity of their articles and for obtaining written permissions from publishers or persons owning the copyright to any previously published and/or copyrighted material.