JULY–AUGUST 2001
NUMBER 215

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

TR NEWS

Evaluating Bridge Health

California's Diagnostic Tool

Also:

Transit Safety on Track

Asphalt for the Ages

Concrete's Next Century

Mines Below Highways

Value Engineering Rewards

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually draw on approximately 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

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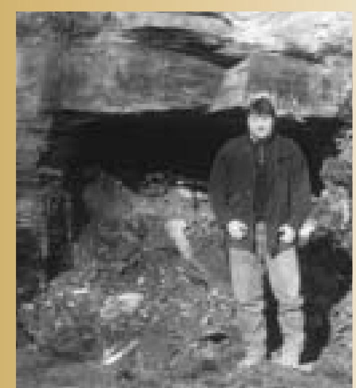

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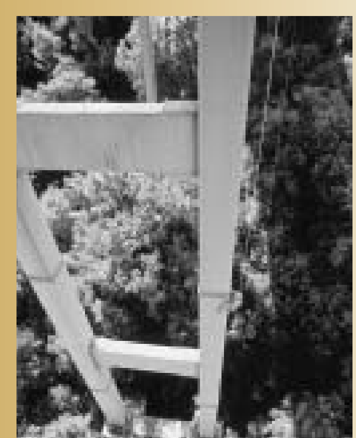

Cover: California Department of Transportation bridge inspector examines health of Cold Springs Canyon Bridge, Santa Barbara (*photo by Dan Tateishi, courtesy of Caltrans*).

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 included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

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ALSO IN THIS ISSUE

LETTERS

Highway Safety Design: A Systems Approach

In their article, "Designing To Improve Highway Safety" (*TR News*, January–February 2001, pp. 50–51), Samuel C. Tignor and Ron Pfefer use the term "systems." I hope the term will be applied broadly in the work of their committees, the Joint TRB Subcommittee on International Human Factor Guidelines for Road Systems Design and the Joint TRB Subcommittee on the Highway Safety Manual.

For instance, will the committees begin with a narrow approach and incorporate traditional assumptions, or will they consider as variables all the significant factors contributing to crash, injury, and fatality levels? A systems approach should include the following issues:

1. Driver licensing. Anyone can get—and keep—a motor vehicle operator's permit; many operate motor vehicles without a valid permit. Suggest actions to get unqualified and bad drivers off the road and keep them off.
2. Vehicle code. Many crashes result from a mindset that "I've got the right-of-way, so I am not required to slow, yield, or stop." Most operators do not know, understand, or care that the vehicle code does not give anyone the right-of-way, but defines who must yield the right-of-way under various circumstances. Consider proposing changes to the vehicle code to hold all parties responsible for doing whatever is necessary to avoid crashes.
3. Enforcement. Many engineers say the problem is that the laws aren't enforced. Still, most drivers treat the speed limit as something to pass through when starting up or slowing down—no one travels at the speed limit. The lack of effective speed enforcement anywhere in the United States is a major contributing factor in the 41,000 motor vehicle deaths that occur each year. Advocate for more effective enforcement, not more "forgiving" roadways.
4. Design speed, posted speed, and operating speed. The American Association of State Highway and Transportation Officials' Green Book and similar state references base design speed on functional classification, but give scant attention to the compatibility of motor vehicle speeds with adjacent land uses and activities. Engineers also use outdated tables and formulas to establish geometric designs. As a result, streets and highways not only accommodate but encourage drivers to exceed the posted speed limit—by 50 percent or more on neighborhood and collector streets and by 30 percent or more on controlled-access freeways. Consider proposing a requirement for professional engineers to certify that a design will result in an 85th percentile speed of no more than 5 mph above the posted speed limit on neighborhood and collector streets as well as on urban arterials.

We must stop allowing the kind of behavior by motor vehicle operators that is killing our children, our parents, our friends, and our neighborhoods. Forgiving highways will not protect people from bad drivers and poorly designed roadways.

—Bill Wilkinson
National Center for Bicycling & Walking

Developing Safety and Operating Standards for Rail Transit

ONLINE, ON TIME, AND ON TRACK

THOMAS PEACOCK

The author is Director of Operations and Technical Services, American Public Transportation Association, Washington, D.C.

The increasing popularity and demand for rail transit has led many systems to plan expansions and a growing number of cities to plan rail transit startups. Leaders of the public transportation industry agree that now is the time to develop guidance for growth and to establish uniform standards for state oversight of rail transit safety.

Under the umbrella of the American Public Transportation Association (APTA), the rail transit industry has united to develop standards and recommend practices to improve safety and increase operating efficiency. The effort is spearheaded and funded by the leaders of 25 rail transit systems working with the Federal Transit Administration (FTA) and Wabtech, a manufacturer of rail car components.

This project will help rail transit systems meet the public responsibility to improve an already excellent record of safety and reliability. A Rail Transit Standards Policy Committee, chaired by Jack Leary, General Manager of the Southeastern Pennsylvania Transportation Authority, sets the policy and provides top-level guidance for the project.

Assuring Consensus

APTA intends to use an industry consensus process to develop, implement, and maintain standards and recommended practices covering rail transit system design, operation, and maintenance. APTA has patterned the project after a highly successful program conducted by commuter railroad members—the Passenger Rail Equipment Safety Standards (PRESS) program.

The effort is expected to produce uniform and visible safety oversight programs for the states, a best practices resource for the entire industry, guidance for new-start systems, and improved communications among rail transit systems and government agencies.

To be successful, any consensus process involving organizations with diverse interests must have definite rules and procedures. APTA has developed a set of bylaws to govern the process, incorporating the following basic principles:

- Open membership to represent the industry at large;
- An open meeting process;
- A public comment period via the APTA website;
- Response to all reasonable comments;
- Final approval with one vote per organization;
- Maximum use of electronic communication; and
- Implementation through the authority of the APTA Rail Transit Standards Policy Committee.

Structuring the Committees

The Policy Committee has directed APTA to focus on

- Vehicle inspection and maintenance;

APTA Committees for Developing Rail Transit Standards

Vehicle Inspection and Maintenance Committee

Subcommittees

- Daily Inspections;
- Training and Qualifications;
- Car Body Periodic Maintenance;
- Electrical Systems Periodic Maintenance;
- Mechanical Systems Periodic Maintenance; and
- Reliability Methodology To Set Periodic Maintenance Intervals.

Contacts

The committee chair is Jay Shah, General Superintendent, Car Equipment, MTA New York City Transit (718-927-7822, shahjayn@aol.com). David Phelps is the APTA staff support (202-496-4885, dphelps@apta.com), and Gordon Campbell of LDK Engineering provides technical advice (905-577-1052, ldkeng@worldchat.com).

Operating Practices Committee

Subcommittees

- Emergency Preparedness and Accident Investigations;
- General Rules;
- Train Operations; and
- Control Center and Communications.

Contacts

The committee is chaired by Peter Tereschuck, Vice President, Operations, for San Diego Trolley (619-595-4902, ptereschuck@sdti.sdmts.com). Tom Peacock serves as APTA staff support (202-496-4805, tpeacock@apta.com) and Ken Korach of Transportation Resource Associates offers technical support (215-546-9110, ken@traonline.com).

Fixed Structures Inspection and Maintenance Committee

Subcommittees

- Track;
- Signals and Communications;
- Structures (Tunnels, Bridges, etc.);
- Power; and
- Stations.

Contacts

The chair for the committee is James Dwyer, Director, Technical Support, Port Authority of Allegheny County (412-488-3072, jdwyer@portauthority.org). Frank Cihak provides APTA staff support (202-496-4880, fcihak@apta.com) and Peter Gentle of STV serves as technical adviser (215-832-3524, gentleps@stvinc.com).

Grade Crossings Committee

Subcommittees

- Public Outreach and Education;
- Gated Crossings;
- Nongated Crossings; and
- Safety Assessment Methodology.
- Grade Crossing Inspection and Maintenance.

Contacts

Ron Swindell, Assistant Vice President, Engineering, for Dallas Area Rapid Transit, chairs the committee (214-749-2936, rswindell@dart.org). Phil Olekszyk of World Wide Rail, Inc., provides staff support on behalf of APTA (410-544-0053, wwrail@aol.com), and Nicholas Bahr of Booz Allen & Hamilton offers technical support (703-377-0372, bahr_nicholas@bah.com).

Note: The APTA Rail Transit Standards Policy Committee, chaired by Jack Leary, General Manager of the Southeastern Pennsylvania Transportation Authority, provides overall guidance for the project committees.

- ◆ Operating practices;
- ◆ Fixed structure inspection and maintenance;
- ◆ Grade crossings; and
- ◆ Vehicle crashworthiness.

APTA established a working committee to develop standards and recommended practices in each area except vehicle crashworthiness. The American Society of Mechanical Engineers, a professional group active in setting standards, will draft rail transit vehicle crashworthiness standards with assistance from APTA.

APTA has assigned an experienced staff member and has hired a recognized rail transit industry consultant to facilitate and assist the work of each committee. In November 2000, APTA invited the participation of rail transit agencies, rail transit system integrators and car builders, major component suppliers, rail labor organizations, and government agencies with an interest in the rail transit industry.

More than 180 individuals have volunteered to participate on one or more of the committees—including representatives from the United Transportation Union, FTA, the Federal Railroad Administration, and the National Transportation Safety Board. APTA actively continues to seek volunteers, particularly from other rail labor organizations and from businesses supporting the rail transit industry.

Each of the four committees held an initial organizational meeting to elect a chairman, organize working groups, set priorities, and develop work plans and timelines. The sidebar on page 4 shows how the committees have organized to execute their work plans.

APTA staff and the consultants assist each working group and its subcommittees. Nonetheless, the consensus process is a "roll up the sleeves" effort—every member of a subcommittee contributes expertise and knowledge to the subcommittee's product.

Facilitating Participation

To curtail costs for travel and mailings, APTA plans to use the Internet to communicate with committee members and to post work products for review. The first meeting of each committee included a tutorial on how to use a version of Webworks customized for this project by Booz Allen and Hamilton. Each subcommittee has a website for posting reference documents. Subcommittee members also can post work for comment or for use by other subcommittee members.

To spread the travel burden equally, APTA plans to rotate locations across the country for the meetings of each committee. To volunteer to participate or to obtain more information about the activities of a committee, please contact the committee chair or the APTA staff support person listed in the sidebar on page 4.

The schedule calls for the first few standards and recommended practices to be ready for a vote by November 2001. As other standards follow, the benefits of the project will begin to have an impact on the entire rail transit industry.

This consensus effort is a bold step to improve safety and operating efficiencies for rail transit in the United States. The time is right. The partnerships APTA has established will help the rail transit industry meet its challenges in a time of unprecedented growth and opportunity.

TCRP Project Comes Aboard

In June, the APTA Rail Transit Standards Policy Committee allocated funds to begin incorporating into its work the efforts of Transit Cooperative Research Program (TCRP) Project G-4, *Developing Standards for System and Subsystem Interfaces in Electric Rail Passenger Vehicles*. TCRP launched this project in 1996 to provide a process for the transit industry to establish standards voluntarily. The project employs procedures established by the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of Mechanical Engineers (ASME) to develop industry consensus standards.

To date, 15 working groups involving more than 300 representatives of transit agencies, vehicle and component manufacturers and suppliers, consultants, government agencies, and others have met to develop technical standards. IEEE has balloted, approved, and published nine standards covering

- ◆ Communications Protocol on Trains (IEEE 1473-1999);
- ◆ Communications-Based Train Control Performance and Functional Requirements (IEEE 1474.1-1999);
- ◆ Functioning of and Interfaces Among Propulsion, Friction Brake, and Trainborne Master Control on Rail Rapid Transit Vehicles (IEEE 1475-1999);
- ◆ Passenger Train Auxiliary Power Systems Interfaces (IEEE 1476-2000);
- ◆ Passenger Information Systems for Rail Transit Vehicles (IEEE 1477-1998);
- ◆ Environmental Conditions for Transit Car Electronic Equipment (IEEE 1478-2000);
- ◆ Rail Transit Vehicle Event Recorders (IEEE 1482.1-1999);
- ◆ Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control (IEEE 1483-2000); and
- ◆ Rotating Electric Machinery for Rail and Road Vehicles (IEEE 11-1999).

Work is continuing on 11 other IEEE standards. In addition, two ASME working groups are developing crashworthiness standards for light rail and rapid transit vehicles. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers also is considering assistance in the development of a standard for railcar heating, ventilating, and air conditioning. The rail transit industry has applauded the standards-development efforts sponsored by the TCRP project.

California Bridge Health Index

A Diagnostic Tool To Maximize Bridge Longevity, Investment

RICHARD W. SHEPARD and MICHAEL B. JOHNSON

Richard W. Shepard is Supervising Bridge Engineer, and Michael B. Johnson is Senior Bridge Engineer, California Department of Transportation, Sacramento.

The California Department of Transportation (Caltrans) is responsible for 12,656 bridges with an estimated asset value of more than $35 billion. To manage the work performed on this vast inventory, Caltrans has developed a versatile diagnostic tool, the California Bridge Health Index.

The Health Index is a single-number assessment of a bridge's condition based on the bridge's economic worth, determined from an element-level inspection. The index makes it possible to ascertain the structural quality of a single bridge or a network of bridges and to make objective comparisons with other bridges or networks. Caltrans has discovered many management applications for the Bridge Health Index, including performance measurement, resource allocation, budget management, and choosing the best option for a bridge's preservation.

Caltrans has been involved since 1989 in the development and implementation of the Pontis Bridge Management System, a product of the American Association of State Highway and Transportation Officials (AASHTO). Pontis has introduced many enhancements to bridge maintenance and rehabilitation—most notably the element-level inspection, which provides a quick assessment of a bridge's condition by encapsulating the severity and the extent of any problems.

The availability of element-inspection information and the need to measure bridge condition accurately were key to the development of the California Bridge Health Index. Unlike the Federal Highway Administration's (FHWA's) Sufficiency Rating, the Health Index provides insight into the structural condition of a bridge without regard to the bridge's functional adequacy.

Inspection Standards

In December 1967, 46 people died in the collapse of the Silver Bridge in West Virginia. Since then, the federal government has monitored the condition of the nation's bridges, developing the National Bridge Inspection Standards and the National Bridge Inventory (NBI). The NBI contains information about every bridge on a public road—more than 575,000 bridges.

For more than 25 years, states have reported NBI inventory data annually, as required by the Federal Recording and Coding Guide. The Coding Guide defines 96 specific data describing a bridge's location, geometrics, age, traffic, load capacity, structural condition, and other relevant features.

Sufficiency Rating

The Coding Guide includes a procedure to calculate a bridge's Sufficiency Rating, which combines the functional and condition data in the NBI into a single number from 0 to 100. The federal government uses the Sufficiency Rating in allocating funds for the Highway Bridge Rehabilitation and Replacement (HBRR) Program and in determining eligibility criteria for bridge projects that use these funds.

Many perceive the Sufficiency Rating as representing the structural condition of a bridge—the lower the number, the worse the condition. However, the Sufficiency Rating combines data on function and condition and is not therefore an accurate tool for determining a bridge's condition.

Functional Information

The NBI data that describe the service a bridge provides to a roadway often are termed functional data. These data describe the type of traffic carried by the bridge as well as the bridge's capacity in relation to traffic demand. A bridge that is not wide enough, high enough, or strong enough to meet traffic demand is functionally obsolete. The NBI data can identify functionally obsolete bridges.

Condition Information

The NBI records the structural condition of a bridge primarily through three items that represent major bridge components: the deck, the superstructure, and the substructure. The condition of these elements is assessed on a rating scale of 0 to 9, with 0 as the lowest or worst condition and 9 as the best.

These ratings provide information on the severity of a condition but do not identify or quantify the extent of the problem. The failure to identify or quantify the extent of a deficiency minimizes the effectiveness of NBI condition ratings in determining maintenance and rehabilitation needs.

NBI condition ratings also are vulnerable to subjective interpretation by bridge inspection staff. Since multiple distress symptoms may adversely affect the ratings that describe the general condition of a bridge, the inspection staff must decide which distress symptom most represents the bridge's general condition, introducing subjectivity into the ratings.

For example, a large bridge has many columns, only one of which is in poor condition. If the rest of the bridge is in good condition, what is the overall condition of the bridge? The NBI evaluation would dismiss the severity of a localized problem and report the bridge to be in good condition overall. However, if the localized problem condition spreads, at what point would it affect the bridge's overall condition? The NBI condition ratings do not account for this dilemma.

As part of Caltrans bridge inspection program, engineers use an under-bridge inspection truck to inspect fracture-critical elements on a bridge over the Stockton Channel.

Close-up inspection of deteriorated bridge member.

Element-Level Inspection

To eliminate the subjectivity in the NBI condition ratings and to allow recommendations for specific action, FHWA's Demonstration Project No. 71 guided development of a new element-level inspection procedure. The effort culminated in the creation of the *CoRE-AASHTO Guide for Commonly Recognized Structural Elements*, often called the "CoRE Element Manual."

The CoRe Element Manual defines each element and the terms for associated condition states. FHWA has endorsed the manual, which is maintained by AASHTO.

The element-level inspection techniques differ from the NBI in several important ways. Most obvious is the more detailed breakdown of the bridge components. Instead of the NBI's single superstructure rating, element-level inspection requires individual condition assessments for girders, floor beams, pins, hangers, and so on. The element inspection techniques improved on the NBI by defining each element's condition state in precise engineering terms.

The inspection supplies the totals of each element and the numbers of the element in each condition state. With element-level inspection information, actions specific to the element type, the material makeup, the severity of the deterioration, and the quantity of the deterioration can be determined. Element-level inspection is arguably the single most significant accomplishment of bridge management system developments to date.

The more detailed element inspection information has enabled many improvements in bridge management and is the basis for the California Bridge Health Index.

New Performance Measure

The Sufficiency Rating did not meet California's need for a single number to measure the performance of maintenance and rehabilitation. Therefore Caltrans developed the California Bridge Health Index, a numerical rating of 0 to 100 that reflects element inspection data in relation to the asset value of a bridge or network of bridges.

The premise of the Health Index is that each bridge element has an initial asset value when new. An element may deteriorate to a lower condition state, reducing its asset value. With maintenance or rehabilitation, the condition of the element is likely to improve and the corresponding asset value to increase.

Field inspection can ascertain the element condition-state distribution at any point in time, or a deterioration model may predict it. Once the condition distribution is known, the current element value can be determined for all elements on the bridge. The Health Index for the bridge is the ratio of the current element value to the initial element value of all elements on the bridge (see sidebar below for the formulas). To apply the Health Index concept to a network of bridges, the entire network is treated as one large structure containing the summation of all element quantities and condition distributions within the network.

Calculating a Bridge's Health Index

Following are the formulas for the computation of the California Bridge Health Index:

$$HI = \left(\sum CEV / \sum TEV\right) * 100$$

$$TEV = TEQ * FC$$

$$CEV = \sum (QCS_i * WF_i) * FC$$

$$WF = [1 - (\text{Condition State \#} - 1)(1/\text{State Count} - 1)]$$

where

HI = Health Index;

CEV = current element value;

TEV = total element value;

TEQ = total element quantity;

FC = failure cost of element;

QCS = quantity in a condition state; and

WF = weighting factor for the condition state.

TABLE 1 Element Distribution for a Sample Bridge

Element Description	Units	Total Quantity	State 1	State 2	State 3	State 4	State 5	Unit Failure Cost (FC)
Concrete Deck	Sq. m	300			300			$600
Steel Girder	m	100	61	34	5			$3,500
RC Abutment	m	24	24					$7,700
RC Column	ea	4	4					$9,000
Joint Seal	m	24			24			$556

RC = reinforced concrete

Tables 1–3 present an application of the Health Index formulas to data from a sample bridge. The final calculation of the sample bridge's Health Index (HI) is as follows:

$$
\begin{aligned}
\text{HI} &= \left(\Sigma\ \text{CEV}/\Sigma\ \text{TEV}\right) * 100 \\
&= (\$622{,}300/\$764{,}144) * 100 \\
&= 81.4
\end{aligned}
$$

Health Index Uses

The Health Index has had a positive impact on the management of bridges in California. The state uses the Health Index to allocate resources, to evaluate district bridge maintenance and rehabilitation, and to provide level-of-service indicators. California also is developing additional applications of Health Index concepts for evaluating annual budget strategies and the life-cycle performance of maintenance and rehabilitation.

Measuring Performance

Caltrans operates and maintains the state highway system through 12 regional district offices. Each district is responsible for the repair and rehabilitation of the highway system and its bridges to meet a required level of service. The level of service is a direct result of the available resources and the management strategies to preserve the system.

Figure 1 shows how the Bridge Health Index is used to judge the performance of each district's management strategies with the resources available. The goal is to have no more than 5 percent of the state's bridges with a Health Index below 80. The bridge management activities of districts that do not meet this goal are evaluated on their ability to make positive advances.

Caltrans uses the Health Index as a performance measure. To convey the physical condition of a bridge to a layperson, Caltrans has developed a visual representation of the Health Index (Figure 2) using the condition-state definitions from the element-level inspection. The visual representation is used to define the levels of service for the maintenance and rehabilitation of bridges.

TABLE 2 Total Element Value of Sample Bridge

Element Description	Calculation	Resulting TEV
Concrete Deck	300 * 600	$180,000
Steel Girder	100 * 3500	$350,000
RC Abutment	24 * 7700	$184,800
RC Column	4 * 9000	$36,000
Joint Seal	24 * 556	$13,344
	Total (Σ TEV)	**$764,114**

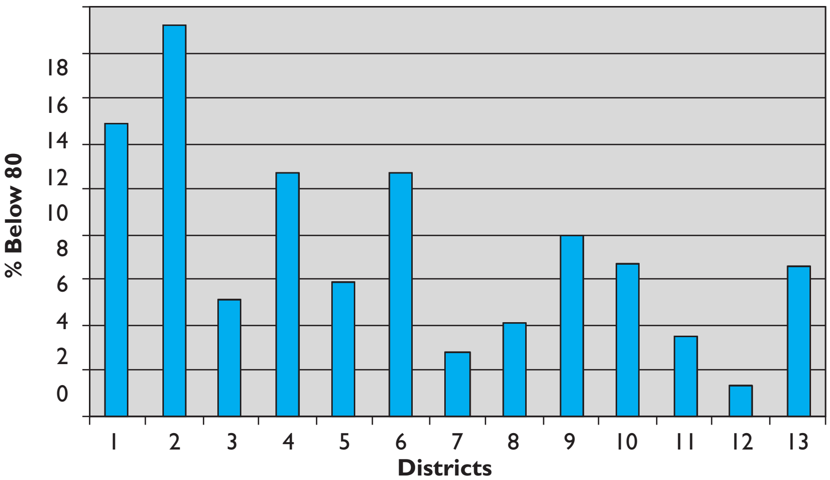
TEV = total element value; RC = reinforced concrete

TABLE 3 Current Element Value of Sample Bridge

Element Description	Calculation	Resulting CEV	Element Health
Concrete Deck	300 * 0.5 * 600	$90,000	50.00
Steel Girder	[(61 * 1.0)+(34 * 0.75)+(5 * 0.5)] * 3500	$311,500	89.00
RC Abutment	24 * 1.0 * 7700	$184,800	100.00
RC Column	4 * 1.0 * 9000	$36,000	100.00
Joint Seal	24 * 0.0 * 556	$0	00.00
	Total (Σ CEV)	**$622,300**	

CEV = current element value; RC = reinforced concrete

FIGURE 1 Percentage of bridges in each district with a Health Index below 80; District 13 represents the statewide average.



Data used to generate California Bridge Health Index involve careful measurements.

Allocating Resources

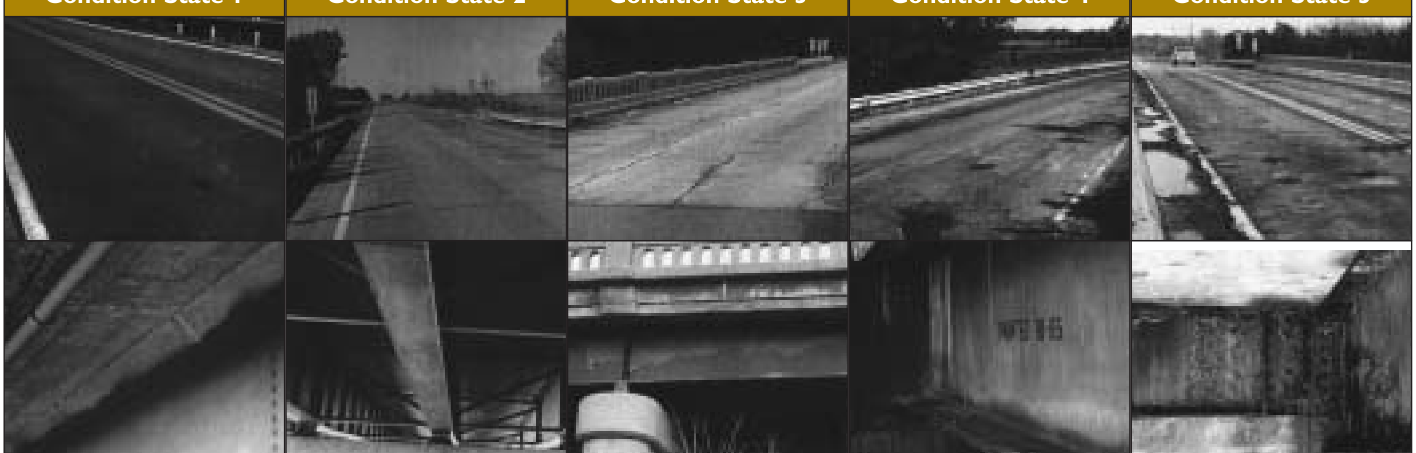
Caltrans has developed a formula for allocating resources to each district, based on the district's size, makeup, and the congestion of the bridges. If the bridges were all the same type, size, and condition, and subject to the same congestion, this baseline would be consistent for all districts. However, resource shortfalls, operating practices, and environmental issues cause differences in each district's network condition.

A district's network Health Index is used to adjust the allocation formula so that the base allocations increase proportionately for bridge inventories that have a poor network Health Index. This allocation procedure is under evaluation and is not accepted practice, however, it has assisted in the distribution of resources.

Budget Decision Making

Bridge managers often must evaluate the impact of several budget scenarios on the condition of a bridge network; this requires applying the Health Index concepts to future conditions. Most bridge management software programs predict actions based on modeling logic, selecting actions that meet the available budget. Budget constraints limit the number of actions that the management system software can select, reducing the Health Index for the network.

FIGURE 2 Visual representation of Health Index values.



Condition State 1	Condition State 2	Condition State 3	Condition State 4	Condition State 5
Number of all bridges in Condition State 1	Number of all bridges in Condition State 2	Number of all bridges in Condition State 3	Number of all bridges in Condition State 4	Number of all bridges in Condition State 5
6771 (55.7%) BHI Range: 100	3422 (28.1%) BHI Range: 99–90	1016 (8.36%) BHI Range: 89–80	290 (2.38%) BHI Range: 79–70	641 (5.28%) BHI Range: <70

By evaluating the change in the network Health Index, it is possible to represent the future condition and the change in the value of the network as a whole based on any budget. The link that the Health Index provides between condition and asset value allows bridge managers to translate condition to dollar amounts.

Figure 3 graphs a budget-based Health Index for four sample funding levels over 10 years. Comparing the results for aggressive funding with those for minimal funding, a bridge manager can demonstrate the change in the Health Index over time based on the various budget options. The key feature of the Health Index is that a bridge manager can correlate bridge condition directly to asset value.

To demonstrate this concept, assume that the aggressive funding level shown in Figure 3 is $10 million per year and the minimal funding curve represents $1 million annually. If the overall asset value of the network is $30 billion and the percentage change in the Health Index between these two funding alternatives is 41 percent, then the reduction in asset value by opting for the minimal funding scenario is $12.3 billion over 10 years.

Therefore opting for the minimal funding plan would reduce expenditures by $90 million over 10 years, but would cost the agency $12.3 billion in asset value. AASHTO has recognized the value of the budget-based Health Index and has incorporated the concept into the current release of Pontis.

Measuring Improvement

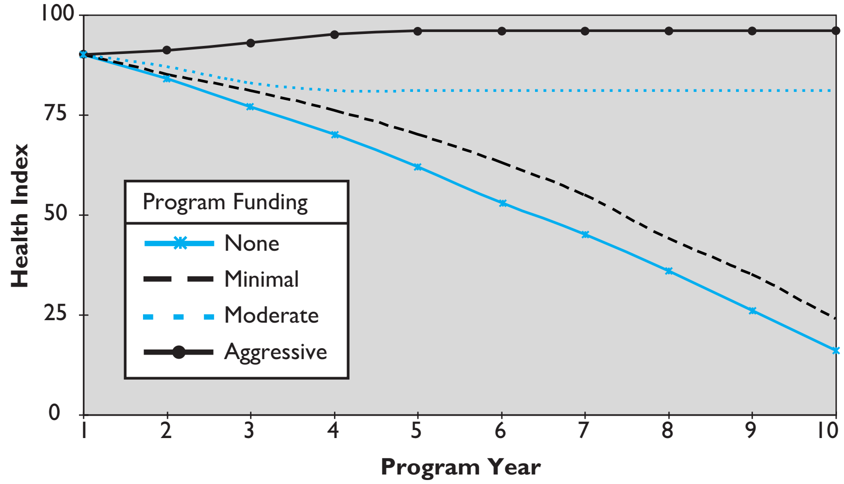
A primary goal of any bridge program is to maintain the condition of the structures by identifying the need for—and then performing—preservation. Often several options must be compared.

Bridge management software generally identifies preferred preservation actions based on benefit-cost analysis. The Health Index allows the bridge manager also to determine how the action would increase the asset value and extend the expected life of the bridge.

Figure 4 illustrates a sample Health Index over time that includes a major project in Program Year 5. The major action in Program Year 5 produces a dramatic increase in the Health Index—a 38 percent increase in asset value. The number of years it would take until the bridge reverts to the same Health Index before the remedial action is the extended life that action has provided to the bridge.

Any action or combination of actions has an initial cost and also a benefit measured by the change in asset value and the increase in life expectancy. Coupling economic optimization with the Health Index can provide the bridge manager with a picture of the cost, condition, and increased life expectancy of any project.

FIGURE 3 Budget-based Health Index for four funding levels over 10 years.

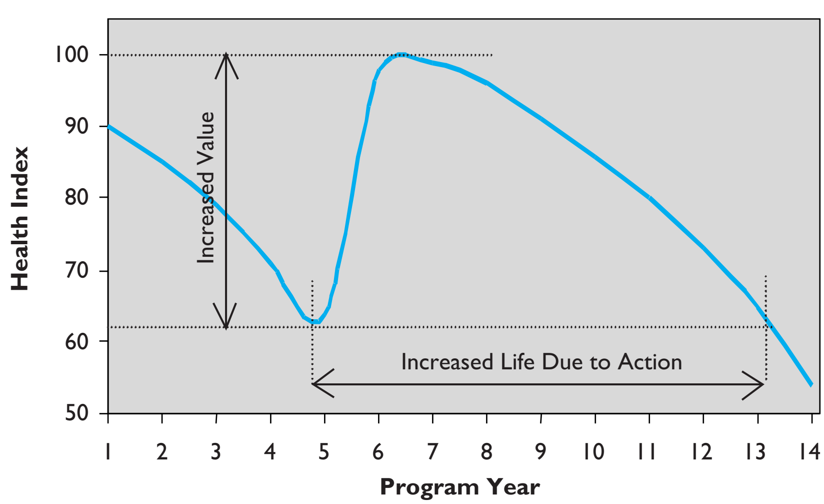


Proven Value

The California Bridge Health Index has proved effective in understanding the overall condition of a bridge or network of bridges. It has proved valuable in connecting desired levels of service with the performance and the allocation of resources for bridge maintenance and rehabilitation.

Moreover, with sophisticated bridge management system software such as Pontis, predicting a bridge's future Health Index based on ongoing deterioration—with or without maintenance actions—is no longer a complex task. This benefit of relating physical condition to asset value promises to make the Bridge Health Index an integral part of bridge management, not only in California but worldwide.

FIGURE 4 Health Index for a bridge over 14 years, showing increased life due to a major project in Program Year 5.



Extended-Life Asphalt Pavement

New Approaches To Increase Durability

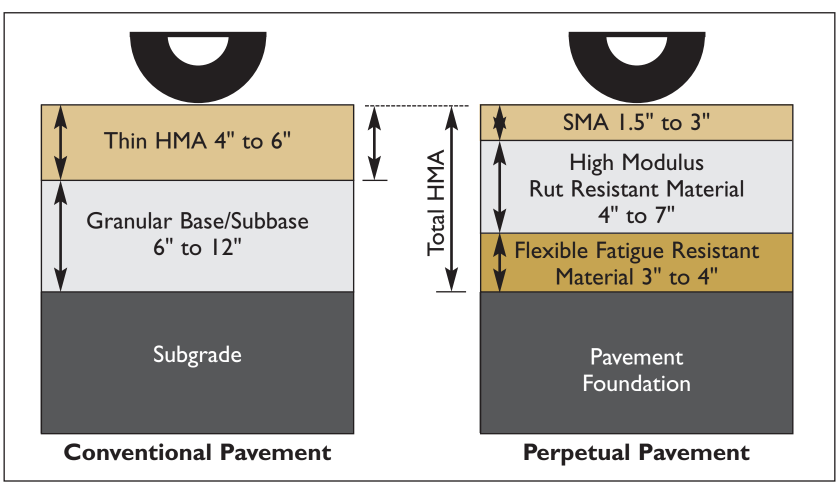
FRANK FEE

The author is Asphalt Pavement Technologist, CITGO Asphalt Refining Co., Moylan, Pennsylvania, and serves on the TRB Committee on General Issues in Asphalt Technology and of two National Cooperative Highway Research Program project panels.

Imagine constructing asphalt pavements that could last for 50 years or more—that is, 30 years longer than typical asphalt pavements. The asphalt industry calls the concept "perpetual pavement," and recent research reports indicate the name may be appropriate.

The reports come from Britain, France, and various parts of the United States, but offer a common perspective—asphalt pavements can be designed to last almost indefinitely. The premise is that an asphalt pavement constructed on a good-quality base with sufficient thickness will not develop the classic fatigue cracking that leads to failure of the pavement. With only periodic renewal of the surface, the asphalt pavement could last a long time. Figure 1 compares typical cross sections of conventional and perpetual pavements.

FIGURE 1 Comparison of structures of conventional pavement and perpetual pavement. (HMA = hot-mix asphalt; SMA = stone matrix asphalt)



Several nations—including the United Kingdom, France, Germany, and the Netherlands—have formed the European Long-Life Pavement Group (ELLPAG)[1], to develop optimal strategies for designing and maintaining long-life pavements. ELLPAG is coordinating research as well as promoting understanding and application of the approach throughout Europe.

U.S. transportation agencies also are looking for longer-lasting pavements. With traffic density always increasing, minimizing delays has become a priority for most transportation agencies. The use of warranties and design-build contracts by agencies in the last decade was an attempt to increase service life and reduce closures on newly designed roadways; perpetual pavement would achieve the same goal.

United Kingdom: "Curing Curve"

Researchers in the United Kingdom began looking into the perpetual pavement phenomenon more than six years ago. They found that thick asphalt pavements had no cracking in the asphalt base course; the cracking started at the surface and progressed downward into the top lifts only. Further evaluation of the in situ strength with falling-weight deflectometer (FWD)-type testing confirmed that the pavement structure was sound and serviceable.

The theory is that as the asphalt mix ages, the surface hardens more than the base lift, initiating cracks at the surface. However, as the thick base course stiff-

[1] For more information about ELLPAG, contact David Gershkoff, Group Secretary, dgershkoff@trl.co.uk, or Brian Ferne, Chair, bferne@trl.co.uk.

ens, its qualities actually improve. The increased stiffness of the base course reduces the deflection of the pavement structure caused by traffic and therefore increases the fatigue life of the roadway.

As the work progressed, researchers proposed the concept of a "curing curve" for asphalt pavements. The asphalt base stiffens fairly quickly within the first 20 years of service life, but then levels off. This suggests a different design and maintenance strategy: at an appropriate time, mill off the cracked surface layer and replace it with a new, high-quality wearing layer.

After extensive evaluation of different roadway types, the U.K. researchers have concluded that the asphalt pavement must be at least 8 inches thick to achieve extended life. The researchers recognize that the minimum thickness of any pavement must relate to the traffic loading and the strength of the subgrade; however, a minimum threshold limit of pavement thickness and strength must be established, either in a new design or in a functioning roadway.

France: Stiffening the Binder

France began to develop extended-life asphalt pavements as a secondary result of the 1980s oil embargo. Development began with the use of very stiff (10/20 pen) asphalt binders in an attempt to reduce layer thickness but maintain overall pavement stiffness, decreasing the demand for asphalt cement.

The result was high modulus asphalt concrete (HMAC). Designed with the stiff asphalt binder and a relatively high binder content, the HMAC has half the air voids and 35 percent more stiffness than conventional mix. Laboratory and full-scale accelerated testing have confirmed that HMAC would provide greater resistance to rutting and to fatigue cracking.

Since France has a relatively moderate climate, thermal cracking has not been a problem; however, in the one area where the temperature drops to –10°C, a very hard asphalt cement showed cracking in the first winter. Pavement designs currently use this material in the base courses; the wearing surface may contain modified asphalt for protection against thermal cracking.

California: Elastic Analysis

A California project, the I-710 Freeway, offers one U.S. approach to designing a long-life pavement. The project used the same concepts for the new full-depth asphalt pavement sections as well as for the rehabilitated (or crack-and-seat) portland cement concrete section. A mix design and analysis procedure developed under the Strategic Highway Research Program was validated with a full-scale heavy-vehicle simulator. In its 30-year design life, the I-710 pavement is expected to carry more than 200 million equivalent single-axle loads (ESALs).

The full-depth asphalt concrete pavement design relied on multilayer elastic analysis. To mitigate bottom-up fatigue cracking, the principal tensile strain on the underside of the asphalt layer was determined; the vertical compressive strain at the top of the subgrade also was determined, to minimize the rutting in the asphalt layer that results from deformation in the unbound layers.

The lower lift of the asphalt base course in the new asphalt concrete section used a "rich bottom" design. This is essentially the same mix used for the base course but with an additional 0.5 percent asphalt binder. The intent is to increase the compactibility and density of the mix, which is placed directly on the subgrade. The mix should be more resistant to fatigue cracking and to moisture penetration.

The entire base course will have a relatively stiff asphalt binder (AR8000 grade) to enhance the stiffness of the mix. The top lift, made with modified asphalt (PBA 6-A grade), will provide optimal resistance to rutting and top-down cracking. A thin, open-graded friction course will serve as the wearing surface. This course will reduce tire spray and hydroplaning in wet weather and will decrease tire noise. Because the lift is thin (less than 1 inch) it also can act as the "sacrificial" course that protects the structural layers—yet it will be economical to mill and replace periodically.

In 1993, after 26 years of service, New Jersey I-287 (*above*) appeared to be in terminal condition.

After 7 years of service with the top 4 inches of surface replaced, New Jersey I-287 remains in good condition today.

Texas: Mechanistic Approach

Like California and many other states, Texas is experiencing the pressures of ever-increasing traffic density and public demand to minimize roadway disruptions. The Texas effort to develop extended-life pavements relies on more conventional materials and a mechanistic design approach.

Core sample from I-287, showing top-down cracking.

The project has designed pavement materials and thickness to limit the tensile strain at the bottom of the hot-mix asphalt (HMA), so that the critical vertical compressive strain on the top of the subgrade would not be exceeded for the extended pavement life. The indirect tensile strength at failure and the resilient modulus were used to determine the design criteria. This approach applied the same concepts as the California project—namely the use of a rich-bottom first lift, a stiff base course, and a high-performance, renewable surface.

New Jersey: Infrastructure Uses

Extended-life pavement concepts also have applications to existing infrastructures. The New Jersey Department of Transportation (DOT) has developed this approach after investigating an interstate highway. The surface of the 26-year-old, 10-inch asphalt pavement, which had received minimal maintenance, appeared to be in terminal condition (see photograph, page 13). The slow and middle lanes of the six-lane roadway had severe fatigue cracking, wheel-path longitudinal cracking, and rutting deeper than 1 inch.

Cores taken from the roadway during the design evaluation showed that the cracks were top-down, with none extending more than 3 inches downward from the surface (see photograph above). Subsequent FWD analysis confirmed that the pavement was structurally adequate. Recovered binder from the cores showed age-hardening to a 20 penetration (similar to the French HMAC). As a result, the New Jersey DOT replaced only the top 4 inches of the pavement, milling 3 inches off the surface and replacing it with 2 inches of a conventional HMA base course and 2 inches of a polymer modified surface course.

The estimated rehabilitated structural capacity was determined to be 69 million ESALs. The 20-year design life was estimated at 50 million ESALs. The rehabilitation is now seven years old and shows no signs of cracking or rutting.

Florida: Promising Research

Most industry experts agree that thick or stiff asphalt pavements will develop top-down cracking. Preliminary findings from ongoing research in Florida suggest a new concept, "time of low crack growth," which models a phenomenon many have observed in the field—cracks start in the pavement surface but grow extremely slowly. The model explains pavements 26 years old with cracks that only penetrate 3 inches from the surface.

Validating this model may provide pavement designers with critical input for determining when a crack may speed up. The findings also may have implications for new approaches to rehabilitation and may provide insight for developing crack-resistant surfacing materials. This ongoing work and other similar projects offer the potential for a better understanding of the phenomenon of top-down cracking and for improved approaches to mitigate the problem.

Adding Years

In summary, an extended-life asphalt pavement has a minimum of 8 inches of HMA; typically the pavements are 12 to 14 inches thick. The pavement components are a sound or improved subbase and base with good drainage, a fairly high modulus HMA base course, and a relatively thin (1.5 to 3 inches) high-performance wearing surface.

The essential concept is that a thicker, stiffer pavement section will reduce traffic-caused deflections of the asphalt layer so that classic bottom-up fatigue cracking will not occur. With a high-performance, thin surfacing material and a "mill and fill" of the surface every 15 to 20 years, the roadway theoretically could last for 50 years or more.

Acknowledgments

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Creating a New Generation of Concrete

Public-Private Partnership Sets Research Agenda

LAWRENCE W. COLE

The Federal Highway Administration (FHWA) and the concrete paving industry—through the Innovative Pavement Research Foundation (IPRF)—have developed a partnership for concrete pavement research and technology development, with funding from the Transportation Equity Act for the 21st Century (TEA-21). The Concrete Pavement Technology Program (CPTP) is pursuing four goals for the U.S. highway system: reduce delays, reduce cost, improve performance, and foster innovation.

Establishing a Tradition

The concrete pavement industry's tradition of applied research dates back to 1889, when George W. Bartholomew proposed the first concrete pavement to city officials of Bellefontaine, Ohio. Although the first automobile would not appear for another 10 years, Bartholomew was convinced that the cement he had produced in his small laboratory could form a hard, durable paving surface.

After two years of convincing citizens and city officials and after agreeing to donate the materials, Bartholomew received permission to build America's first concrete pavement. He also posted a \$5,000 performance bond and a guarantee that the pavement would last for five years.

The first section of concrete pavement, an 8-ft-wide strip of Main Street along Bellefontaine's Courthouse Square, was completed in 1891 and became an immediate success. Local businessmen petitioned to pave the entire block around the square with concrete. America's first concrete pavement is still in service, a testament to the industry's commitment to research and to the durability of concrete pavement.

The author is Vice President, Engineering and Research, American Concrete Pavement Association, Skokie, Illinois, and serves on TRB's Committee on Rigid Pavement Design and the Long-Term Pavement Performance Committee.

Today's challenge for long-lasting pavement repair and replacement is complicated by traffic congestion and by the imperative for worker and public safety.

Today's Challenge

In the 20th century, research and innovation have produced impressive technical advances as the concrete paving industry has helped to create the most extensive and efficient surface transportation system in the world, the U.S. highway network. Research and development is essential not only to the construction of America's surface transportation system, but also in maintaining the system to serve ever-increasing traffic.

Aging concrete highways have carried more traffic loads than they were designed to accommodate. Today's challenge for long-lasting pavement repair and replacement is complicated by traffic congestion and by the imperative for worker and public safety.

Applied research must develop and refine new design methods and improve concrete pavement materials, construction, and rehabilitation techniques. The solutions also must be cost-effective, providing the maximum value for the dollars invested in the rehabilitation and expansion of highways and airport pavements.

Partnering for Better Pavement

In TEA-21, Congress designated $30 million to conduct applied research for improved methods of using concrete in the construction, reconstruction, and repair of federal-aid highways. This provided an excellent opportunity for the public and private sectors to work together to improve the transportation system.

In 1999, FHWA entered a cooperative agreement with IPRF, a nonprofit organization chartered in 1997 and jointly sponsored by the American Concrete Pavement Association, the Portland Cement Association, and the National Ready Mixed Concrete Association. The public-private partnership developed CPTP to leverage public funds from TEA-21 and contributions from the private sector for research, development, and technology to improve the performance and cost-effectiveness of concrete pavements.

State Involvement

Because state highway agencies have primary responsibility for the design, construction, and operation of the highway system, their full and active participation is imperative in implementing new and improved technology. At the request of FHWA and IPRF, the Transportation Research Board (TRB) has formed the Committee for Research on Improved Concrete Pavements for Federal-Aid Highways to ensure that CPTP is responsive to states' needs.

The TRB committee of 18 members—representing state agencies, industry, and the academic community—reviews the long-range work plan of CPTP, advising on the suitability of the overall goals and the likelihood for success of the identified tasks. The committee also conducts regular progress reviews, commenting on course corrections, promising opportunities, and significant findings.

Four Goals

CPTP has set four goals that address the needs of state highway agencies, the concrete pavement industry, and highway users:

- Reduce user delays,
- Reduce costs,
- Improve performance, and
- Foster innovation.

These goals require CPTP to produce practical, readily useable tools and guidelines, including educational materials, to transfer the new products and techniques into practice.

Reducing User Delays

Although much of the highway system requires pavement rehabilitation or reconstruction, the motoring public objects to frequent repairs and unnecessary delays. The public demands long-lasting pavement repair, resurfacing, and reconstruction completed as rapidly as possible.

Several CPTP initiatives address this issue. A major IPRF study, "Traffic Management Studies for Reconstructing High-Volume Roadways." conducted by the Texas Transportation Institute, has two primary objectives:

1. Study successful projects that have used innovative concrete pavement techniques to rebuild urban highways rapidly; and
2. Conduct feasibility studies as part of the planning of urban reconstruction projects to determine the most effective methods of managing traffic during construction.

55-Hour Interstate Reconstruction

The first of these studies documents a dramatic reduction in user delays on I-10 near Pomona, California, as 2.8 km of concrete pavement, one lane wide, was replaced in a 55-hour period (see top photo, next page). Like many other states, California is experiencing the effects of an aging urban freeway system. With 3,000 lane-kilometers of pavement requiring rehabilitation, California's Department of Transportation (Caltrans) decided to research the best methods for constructing long-life pavement while minimizing traffic delays and inconvenience to the public.

For the initial study, Caltrans selected a 5-km (8-mile) stretch of I-10 near Pomona for rehabilitation, using a series of repeated nighttime closures and one 55-hour weekend closure. The section of concrete pavement, in service since the early 1960s, carries an estimated 240,000 vehicles per day—far more than anticipated for its 20-year design life. Through IPRF, a research team from the University of California–Berkeley observed the 55-hour reconstruction, documenting the activities and the rate of productivity.

The weekend closure of the two outside lanes of eastbound I-10 lasted from 10:00 p.m. Friday until 5:00 a.m. Monday. Public traffic continued in the two inside lanes, separated from the construction zone by a movable concrete barrier. The contractor could earn a $500,000 incentive award for removing and replacing a single lane of concrete pavement 2.8 km (1.7 miles) long during the 55-hour period. If all lanes were not ready for public traffic at the end of the period, damages would be assessed at a rate of $10,000 for each 10-minute period.

The paving contactor, Morrison-Knudsen Corporation of Highland, California, completed the entire pavement replacement within the specified period, qualifying for the $500,000 incentive. The University of California–Berkeley team concluded that, under ideal conditions, as much as 3.4 lane-km could have been replaced.[1]

Near Pomona, California, 2.8 lane-km of concrete pavement was replaced and opened to traffic after a single weekend.

Weekend Intersection Replacement

CPTP also is demonstrating methods to reduce user delays and public inconvenience during work on urban streets that carry heavy traffic (see photo, below). In Kennewick, Washington, three distressed asphalt intersections recently were replaced with concrete pavement, each during a three-day closure. The intersections were closed on Thursday night, rebuilt with full-depth concrete pavement, and then opened for traffic by the following Monday morning.

Through IPRF, the University of Washington and the Washington Department of Transportation (DOT) documented the construction techniques. The final report will describe the traffic management plan, the high early-strength concrete mixture, the construction techniques, the production rates, and other details for public agencies and road builders undertaking similar projects. A videotape will document the process step by step from the intersection closure through the opening of the new concrete pavement to traffic.

[1] The research report and summary reports are available from IPRF at www.iprf.org.

CPTP includes studies of rapid intersection reconstruction to meet one of the program's goals: reducing delays.

Rapid Testing and Construction

Although CPTP is focusing on faster rehabilitation and reconstruction techniques to minimize the impact to road users and adjacent property owners, the quality of the pavement also is a consideration. Quality assurance is needed to assess the pavement's properties; rapid nondestructive testing is important for accelerated paving techniques.

As part of CPTP, FHWA is organizing a hands-on workshop to demonstrate nondestructive testing techniques for concrete pavement. State highway agencies and paving contractors will be able to try out the nondestructive testing equipment and, in some cases, to borrow the equipment from FHWA for use on projects.

Maturity testing—a simple and rapid method for determining concrete pavement's early strength—is a technique that shows exceptional promise. The procedure relates the concrete's time and temperature history to its early strength. Concrete test specimens are made in the laboratory, the temperature of the specimens is monitored and recorded, and the strength is tested at various ages. The relationship between the concrete's age, temperature, and strength—or maturity—is determined.

Maturity testing—a simple and rapid method for determining concrete pavement's early strength—is a technique that shows exceptional promise.

The concrete pavement's time and age are recorded in the field with a maturity meter, which records the pavement's temperature and age. Comparing the field readings with the laboratory results allows for the calculation of early concrete strength. This technique is better than traditional strength testing of concrete beams or cylinders when rapid results are needed or when testing facilities are unavailable during nighttime operations.

Reducing Costs

Using limited resources to the maximum advantage requires careful attention to the immediate construction costs and the life-cycle costs of the pavement. Most agencies seek to reduce costs as much as possible and to compromise pavement performance as little as possible, gaining the longest-term performance and the lowest life-cycle costs for the budget.

CPTP is working to reduce the immediate and life-cycle costs of building and maintaining concrete pavements by creating a better understanding of what influences cost, developing cost-effective design options, and eliminating unnecessary design features and construction requirements.

Life-Cycle Costs

Most state highway agencies use life-cycle cost procedures in selecting a pavement section for new and reconstructed roadways. In most cases, the collective judgments of state highway officials have produced the procedures; few studies have sought to determine the actual life-cycle cost of in-service highways.

As part of CPTP, IPRF is evaluating the life-cycle costs and service life of highways. ERES Consultants, Inc., a division of Applied Research Associates, is conducting the study. Records from state DOT files are being compiled to determine the actual cost to build and maintain sections of interstate highways. The information will be summarized to determine life-cycle costs, rehabilitation frequency, and pavement life. The studies will provide insight to state highway agencies to evaluate, verify, and modify life-cycle cost models. IPRF is conducting three studies, building on knowledge gained from earlier studies of Interstate pavement in Tennessee, Utah, Oklahoma, and Georgia.

Cost-Effective Design

Concrete pavement design involves more than determining the appropriate pavement thickness for specific site, traffic, and climatic conditions. The pavement engineer also must select other design features, including the type and amount of reinforcement (if any), base type, joint spacing, joint sealant, type of shoulder, concrete strength, drainage characteristics, and other properties. The pavement designer must make informed choices, selecting features necessary for good performance while avoiding features that are not cost-effective.

An IPRF study is evaluating the design options available to the concrete pavement design engineer. The goal is to compare benefits of improved performance with the cost of each feature, enabling the most cost-effective concrete pavement design. Features that impart value—that improve performance at the least cost—can be included, and features that add considerable cost with less impact on pavement performance can be avoided. The result will be more cost-effective concrete pavement. Applied Pavement Technology, Inc., Oakbrook Terrace, Ill., is conducting the research.

Concrete Overlays

Concrete overlays are a proven procedure for rehabilitation, widely used throughout the United States for well-worn concrete and for distressed asphalt pavement. Concrete overlays on asphalt pavement—commonly called whitetopping—are one of the fastest-growing concrete overlay options.

Pavement design procedures, however, do not fully account for the complex interaction between the concrete overlay and the underlying pavement. The procedures treat the underlying material as a firm base, often ignoring the structural value of the underlying concrete or asphalt roadway.

IPRF is developing new design procedures for concrete overlays over concrete and over asphalt. Advanced modeling techniques, high-speed computers, and new mechanistic design principles are producing more sophisticated design procedures to meet expected traffic loads. The result will be lower-cost concrete overlays without compromising long-term performance. Transtec Group, Inc., Austin, Texas, is conducting the study for concrete over asphalt; a research team for the study of concrete overlays on concrete pavement is to be determined.

Improving Performance

Better Concrete, Better Roads

Concrete mix design and concrete material performance are receiving increased attention. FHWA has several studies under way at the Turner-Fairbank Highway Research Facility in McLean, Virginia, to improve the performance of concrete in pavement, including the development of

- A test for concrete's coefficient of thermal expansion;
- A way to assess the freeze-thaw durability of concrete that has marginal entrained air content;
- A mix-specific alkali-silica reactivity test;
- Concrete mixtures that minimize shrinkage; and
- A test to evaluate the workability of concrete mixtures.

IPRF also is sponsoring research to improve the concrete used in pavement. In recent years, concrete mixture proportioning has become more complex. In addition to cement, water, and aggregate, concrete often contains fly ash, ground granulated blast-furnace slag, or other cementitious supplements. Various chemical admixtures also are used in types and doses adjusted to the temperature and climate at the paving site. High early-strength concrete usually requires chemical accelerators and—in some cases—special cements or thermal insulation to meet early-opening-to-traffic criteria.

Although most concrete mixtures perform well during construction, occasional problems arise. Some mixtures may exhibit early stiffening, retarded setting, loss of air entrainment, excessive shrinkage, early cracking, or premature deterioration from freezing temperatures. These results may occur when materials individually acceptable in concrete combine or react in an unexpected way.

Through IPRF, Construction Technology Laboratories, Skokie, Ill., is developing practical test procedures and criteria to assess the effects of combinations of materials for concrete pavements. The objective is to identify and avoid potential problems with combinations of materials before the concrete is mixed and delivered to the paving site.

FHWA is striving to improve ultrathin whitetopping performance through accelerated pavement testing at the Turner-Fairbank Highway Research Facility, McLean, Virginia.

Rehabilitation Options

Many alternatives are available for the repair and rehabilitation of concrete pavements. Although several studies have examined various aspects of these alternatives, a systematic process is not available to select the most appropriate. Sponsored by FHWA, work is now under way at Texas Transportation Institute to guide pavement engineers through a series of decisions to identify the proper technique for repair or rehabilitation. The guidelines will include

- Evaluating the pavement condition and type of distress;
- Choosing pavement repair, rehabilitation, or reconstruction; and
- Selecting the best specific materials and techniques.

The final guidelines will be issued in a user-friendly computer program for use by public agencies.[2]

Ultrathin Whitetopping

Ultrathin whitetopping (UTW) is a pavement rehabilitation technique that has expanded rapidly since its inception in the early 1990s. UTW is a concrete overlay, 2 to 4 inches thick, with short joint spacing bonded to an asphalt pavement. It has been

[2] For more information on the guidelines, contact Jim Sherwood, Highway Research Engineer, FHWA, 202-493-3150.

Field demonstrations, such as ultrathin whitetopping repair, are important in the Concrete Pavement Technology Program's education and training efforts.

used to rehabilitate distressed asphalt pavement at intersections, bus stops, urban streets, and general aviation airfields throughout North America.

Much has been learned about UTW in the last decade, but few controlled experiments have evaluated the factors that affect performance. As part of CPTP, FHWA has tested 8 sections of UTW using the Accelerated Loading Facility (ALF) device at the Turner-Fairbank Highway Research Facility (see photo, page 19). Each UTW section was carefully instrumented with strain gauges to provide researchers with better performance data. Transtec Group, Inc., is analyzing the results.

Fostering Innovation

The final goal of CPTP is to incorporate research findings and other innovations into practice. This will be accomplished in two ways: first, educating pavement practitioners about new findings and best practices from concrete pavement research and technology efforts; second, encouraging the development of promising technology for concrete pavement design, construction, and rehabilitation.

High-Performance Concrete

FHWA's High-Performance Concrete Pavement initiative is one of the most successful CPTP partnering efforts, providing opportunities for state highway agencies to try out innovative concrete pavement design and construction concepts on selected portions of highways. By actually building highways with innovative features, states gain first-hand knowledge of the advantages and constraints of new design and construction methods. Paving contractors learn the best techniques for incorporating the new technology into the construction process.

Equally important, FHWA's initiative requires the routine monitoring of each project to ensure a performance comparable or superior to more common design or construction practices. Thirteen states have taken advantage of this initiative to try out a variety of innovations, such as

- Various types of joint sealants—including a no-sealant option;
- Alternate dowel bar materials and dowel bar spacing at transverse joints;

- Fiber-reinforced concrete pavement;
- High-durability concrete mixes;
- Surface texturing techniques to improve safety and ride, as well as reduce noise;
- Thin concrete overlays;
- Concrete containing recycled asphalt; and
- Pavement with a 60-year design life.

FHWA is compiling a summary report presenting the studies in detail.[3]

Implementing New Technology

IPRF also is evaluating new and promising innovations in concrete pavement design, construction, and rehabilitation. A project, Field Trials of Concrete Pavement Products and Processes, aims to encourage state agencies to partner with local contractors and suppliers of material and equipment to implement new technology or improvements.

Public and private agencies can solicit IPRF funding to try new or improved concrete pavement technologies in field conditions. Reports, photos, videotape, and written reports will capture each effort for education and technology transfer. Field demonstrations have been completed or will soon be made on several promising technologies, including

- Techniques for repairing UTW (see photo, facing page);
- Rapid intersection replacement using concrete pavement;
- Thin concrete overlays of distressed asphalt pavement;
- Precast concrete panels for rapid pavement repair; and
- Performance-related specifications for concrete pavement construction.

This effort specifically aims to try out new technologies in field conditions, not to fund product development or laboratory investigations. Transportation researchers, public agencies, and private firms are encouraged to submit proposals to IPRF for consideration.[4]

Demonstrating Pavement Testing

FHWA's mobile concrete laboratory is an important element of CPTP. Housed in a semi-truck trailer, the laboratory travels throughout the United States, demonstrating the latest technology in concrete pavement testing and mixture proportioning. At job sites, the mobile laboratory's technicians help paving contractors and state DOT engineers test concrete with traditional methods and with new technologies. The hands-on demonstration and training is important for bringing the new technologies into use.

Technology Transfer

Each CPTP project includes technology transfer—for example, through funds for publications, videotapes, presentations, and other educational material. CPTP also sponsors workshops to inform transportation officials and industry representatives about new concrete pavement research results and technology advances. FHWA and IPRF have sponsored or are planning several training sessions, including such topics as

- Concrete pavement smoothness;
- Nondestructive testing for concrete pavement;
- Concrete durability; and
- Concrete pavement design.

Beyond TEA-21

Significant progress is being made toward the four goals of CPTP: reducing delays, reducing cost, improving performance, and fostering innovation in concrete pavement for the U.S. highway system. The close working relationship between FHWA and IPRF is an excellent example of a productive public-private partnership. Significant research and technology development is under way, with guidance from state highway agencies provided through the TRB Committee for Research on Improved Concrete Pavement for Federal-Aid Highways.

The four goals of CPTP involve immediate or short-term needs, but the program also is considering the needs of the highway community in 10 to 15 years. It is clear that the needs for improved concrete pavement technology will exceed available CPTP resources; therefore the TRB committee has recommended the development of a long-term plan for concrete pavement research and technology.

Through IPRF, the Center for Portland Cement Concrete Pavement Technology at Iowa State University is developing a long-term plan to extend beyond TEA-21 and CPTP. The plan will broaden CPTP, building on successes and identifying areas and issues that require more work. The research and technology development under way in CPTP—aimed at today's challenges—coupled with a longer-range plan to address the next 10 to15 years, promises to create a new generation of concrete pavement to meet the nation's highway transportation needs.

[3] For a copy of the FHWA summary report contact Mark Swanlund, Concrete Pavement Engineer, FHWA, 202-366-1323; e-mail: mark.swanlund@fhwa.dot.gov.

[4] More information and proposal procedures are posted at the IPRF website, www.iprf.org.

U.S. Roadway Under

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Interstate Group Works To Prevent Dangers from Underground Mines

THOMAS E. LEFCHIK and L. RICK RUEGSEGGER

Exposed mine void beneath State Route 32.

Eighteen-foot trench after excavation of the overburden and mined coal seam. Note the exposed mine openings.

Sinkholes and slides from abandoned and deteriorating underground mines are little-known threats to traveler safety throughout the United States. Transportation agencies must protect roadways and other facilities near old mines, despite a lack of knowledge and experience in dealing with the problem. The potential danger and liability are significant.

Roadway Problems: Ohio

On March 5, 1995, a 12-foot section of Interstate Route 70 in Guernsey County, Ohio, suddenly collapsed when an abandoned underground mine subsided. Three cars and a truck encountered the collapsing roadway and narrowly escaped tragedy. The state closed this vital highway for four months, repairing the water-filled mine by grout injection at a cost of $3.6 million.

This startling incident attracted nationwide attention. However, it was not the Ohio Department of Transportation's (DOT's) first encounter with mines beneath roadways. Maintenance crews periodically had filled road subsidences from mine collapses at other locations. One site was the interchange of I-70 and I-77, among the largest interchanges in the United States.

Subsequent investigations at the I-70/I-77 interchange revealed underground voids within a few feet of the pavement of one of the ramps. The grout injection repair of the mines beneath the interchange cost $4.7 million (see sidebar, page 23).

Ohio has completed other notable mine repair projects on multilane divided highways since 1995. These have included

- The excavation and replacement of 1,700 linear feet of I-470 at a cost of $3 million;
- The excavation of a half mile of State Route 32—the mine depth varied from 7 to 25 feet—at a cost of $5 million[1]; and
- The grouting of an unmapped clay and shale mine beneath U.S. Route 52.

[1] The Ohio DOT website offers a photographic chronicle of the repairs to State Route 32, www.dot.state.oh/mine/.

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mined

Mines beneath and adjacent to roadways are a past, present, and unavoidable future problem that is becoming more prevalent as mines age. Detailed maps from the Division of Geological Survey of the Ohio Department of Natural Resources show approximately 4,200 abandoned mines in Ohio; an estimated 2,000 additional abandoned mines in the state do not have detailed maps (*1*).

Roadway Problems: Other States

Many other states have encountered notable problems with mines beneath roadways. However, the problems and the methods of repair often have not gained publicity. Following are a few examples.

◆ Missouri DOT has investigated a new route that crosses an area of old lead and zinc mines. Problems encountered include old pits, shafts, shallow prospects, subsidences, and piles of tailings (ore residues).

◆ Kansas DOT has repaired many roadways in southeast Kansas affected by subsidences of coal, lead, and zinc mines.

◆ In New York, the flooding and subsequent collapse of a salt mine destroyed a bridge on a state highway.

◆ Active long-wall mining of coal has caused problems in several states, such as Pennsylvania, where mining beneath I-70 in 2000 caused a pavement subsidence of as much as 4.5 feet.

Addressing the Task

Mines can endanger the traveling public by causing pavement collapses, sinkholes in roadway shoulders or side slopes, the settlement of bridges and other structures, and landslides from collapses or drainage. The I-70 site in Guernsey County, Ohio, underscored the potential for severe danger to travellers and for liability to the state.

Ohio DOT personnel recognized the need for a systematic process to address the problem. The number of mines near roadways in the state could be as high as 1,000, making timely remediation at every site impossible.

Ohio DOT therefore developed an abandoned underground mine inventory and risk assessment process to locate and evaluate the condition and safety of mine sites underlying highways. An Ohio

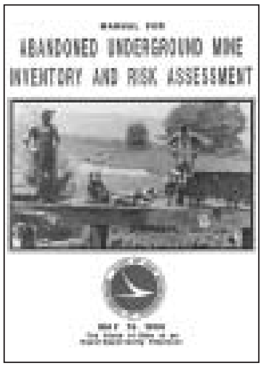
Ohio DOT employee in front of four-foot-high void discovered underneath eastbound lanes of State Route 32.

Refilling Mines Beneath an Interchange

Not long after the 1995 roadway collapse in Guernsey County, Ohio DOT maintenance personnel at the I-70/I-77 Interchange notified state engineers of an ongoing need to fill subsidences adjacent to the roadways and in infield areas. Mine maps from the Ohio Department of Natural Resources Division of Geological Survey showed abandoned mines beneath most of the interchange. However, diaries and other records of the original construction provided limited information about encounters with abandoned mines or about the treatment of mine voids.

Investigative borings approximately every 50 feet along all mainline and ramp lanes of the interchange revealed unmapped mine voids, deteriorating mine roof rock, and progressive overburden failure. Ohio DOT closed one ramp immediately to allow emergency grouting of a void.

Engineers prepared plans for grouting all mine voids beneath the interchange. The repair work proceeded by drilling bore holes 25 feet apart and injecting a grout mixture of portland cement, fly ash, and sand to fill the mine voids. The remedial work affected 5.7 lane-miles of the interchange.



Ohio DOT manual on abandoned mines.

DOT technical manual documents the process (2); the manual is also published by FHWA (3).

Canvassing for Information

During the repair of the I-70 site and the development of the *Abandoned Underground Mine Inventory and Risk Assessment Manual*, Ohio DOT contacted other state DOTs as well as state and federal agencies to determine methods and actions in use to locate, investigate, rate, remediate, and monitor roadways above abandoned mines.

The responses made it evident that the knowledge and experience gained by state DOTs was not widely shared. Other state DOTs were wrestling with the same issues and problems; each state had made successful and unsuccessful attempts, trying various methods and procedures, often repeating unknowingly what others already had tested. The state personnel dealing with mine issues also were encumbered with other responsibilities and pressing issues and consequently could expend only limited effort on mine-related issues.

Clearly, the problems of mines beneath roadways is widespread. The Office of Surface Mining Reclamation and Enforcement of the U.S. Department of the Interior maintains a repository of mine maps—mostly of coal mines—for 45 states (*4*). However, states that do not have maps in the repository also have reported subsidences.

Many transportation agencies must assess or address a potentially large number of sites with mines beneath roadways, but are hindered by a lack of information, knowledge, experience, resources, and time. This situtation has hampered progress in adopting and developing systematic methods to locate, monitor, and address the problem sites.

Call to Cooperation

Ohio DOT convened a workshop in 1997 for state DOTs and state and federal agencies to share knowledge and experiences with mines. FHWA provided funding for the workshop, attended by representatives of nine states and one turnpike authority: Illinois, Kansas, Kentucky, Maryland, Missouri, New York, North Dakota, Ohio, and Pennsylvania and the Pennsylvania Turnpike.

In addition, seven state and federal agencies participated: the U.S. Department of Interior, Office of Surface Mining; the U.S. Geological Survey; FHWA; the Ohio Department of Natural Resources; the Ohio Mine Subsidence Inventory Underwriting Association; the Ohio Environmental Protection Agency; and the Ohio Department of Development.

Discussions focused primarily on procedures to inventory and assess sites, but also covered other aspects of dealing with mines beneath roadways, such as locating mine voids, monitoring conditions, and performing remediation. The workshop produced a lively exchange of information, benefiting all participants, who agreed to continue cooperation and sharing information.

Grouping Up

The Interstate Technical Group on Abandoned Underground Mines, established soon after the workshop, consists of technically oriented personnel responsible for the remediation of underground mines beneath highways. Membership includes representatives of Arizona, FHWA, the Federal Railroad Administration, Illinois, Indiana, Iowa, Kansas, Kentucky, Maryland, Michigan, Missouri, New York, North Dakota, Ohio, Ontario (Canada), Pennsylvania, the Pennsylvania Turnpike, and West Virginia.

The goals of the group are to

- Generate and disseminate information, and
- Obtain outside funding or share the costs of research or other mutually beneficial efforts.

The expected benefits from achieving these goals are

- Increased efficiency and effectiveness of each state's operations, and
- Enhanced safety for the traveling public.

Stimulating Communication

Group members have cultivated contacts from the original and subsequent workshops, generating and disseminating information. FHWA hosts an interactive website, www.fhwa-ohio.org/mine.html, featuring member contact information, a discussion board for group communication, summaries of past workshops, information about upcoming workshops, the Ohio DOT mine manual, and links to related websites. The website soon will add other features, such as information about ongoing and completed research and projects.

Most significant are the website's interactive pages. State members regularly will update information about research and projects completed and under way, assuring that the information is accurate and up-to-date. The data will include the type of work, the location, the date completed, the degree of success, and the availability of a report.

Members use the discussion board to post questions and obtain responses from other members. In this way, group members can draw immediately on the knowledge and experience of others, at the same time assembling on the website a searchable library of practical information accessible to members and the public.

Workshop Agendas

Missouri DOT hosted the Technical Group's second workshop in St. Louis in August 1998, focusing on geophysical methods of investigation and monitoring, but also including discussions of other issues. Representatives from six states—Iowa, Illinois, Kansas, Missouri, Ohio, and Pennsylvania—one state agency, one federal agency, and seven private-sector firms participated. The Technical Group decided to convene a workshop every two years.

In April 2000 Kansas DOT hosted the third workshop in Kansas City, with representatives of nine member states as well as federal and state agencies, private consulting firms, industry, and academia. After presentations by the participating transportation authorities, the workshop examined the roadway applications of geophysical techniques such as ground-penetrating radar, seismic reflection, borehole tomography, time domain reflectometry, surface wave inversion and attenuation, and microseismic monitoring.

Each presentation offered case studies demonstrating the application of geophysical techniques to roadways over abandoned mines. The workshop also included a field trip to an abandoned underground limestone mine being converted to commercial use and for housing a local college library.

Discussions at the Kansas workshop noted that other modes of transportation—specifically railroads—also face hazards with abandoned mines. In addition, other mine-related agencies and firms are dealing with many of the same issues and using many of the same methods for monitoring, investigation, and remediation. The group therefore has invited the involvement of representatives of other transportation modes and mine-related groups.

The group has investigated affiliation with other organizations, but has decided to remain independent. Illinois and Iowa will host the next workshop in 2002 (for information, see sidebar at right).

Shared Research

The group has not yet shared actively in the cost of research. However the sharing of information has prevented states from employing unsuccessful or untried methods, modifying unsuccessful methods, or applying successful methods in untried conditions.

Group members generally choose research topics that suit their needs or interests and then share the results with other states. Pooling funds for a common research project remains a possibility. The group has not yet identified sources of outside funding for research.

Symposium Connects with Technical Group

Two TRB standing committees, on Engineering Geology and on Exploration and Classification of Earth Materials, held a symposium on Abandoned Underground Mines, May 15, 2001, in Cumberland, Maryland, before the 52nd Highway Geology Symposium hosted by the Maryland State Highway Administration. More than 80 people attended the TRB session.

Presentations described transportation projects in abandoned underground mine areas in the states of Missouri, Pennsylvania, and Kansas, and in Ontario, Canada. In addition, participants heard a review of the objectives and contents of the *Manual for Abandoned Underground Mine Inventory and Risk Assessment*, developed by Ohio DOT with input from other state DOTs and federal agencies.

Thomas Lefchik of FHWA presented information on the Interstate Technical Group on Abandoned Mines. The Technical Group will hold its 4th workshop, May 1-3, 2002, in Davenport, Iowa. For information about the Technical Group and the 2002 workshop, contact Lefchik (telephone 614-280-6845, e-mail Thomas.Lefchik@fhwa.dot.gov).

Solid Base

The Interstate Technical Group on Abandoned Underground Mines is making progress on its original goals of generating and disseminating information and of seeking outside funding and sharing in the costs of research and of other efforts of mutual interest. The group members are realizing the benefits of increased efficiency and effectiveness in operations and of enhanced safety for the traveling public. Membership has grown to 18 and remains open to interested agencies.

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Value Engineering Fine-Tuned

Case Study of New Mexico's Success

CHARLIE V. TRUJILLO

The author is Deputy Secretary for Transportation Planning and Design, New Mexico State Highway and Transportation Department, Santa Fe.

With a results-based approach to value engineering—the technique of providing a necessary function reliably at the lowest cost—the New Mexico State Highway and Transportation Department realized more than $140 million in savings in 1999. According to Federal Highway Administration (FHWA) statistics, New Mexico ranked first among state transportation agencies in dollars saved through value engineering and third among states in return on investment.

In partnership with FHWA, the New Mexico State Highway and Transportation Department aggressively pursues value engineering through the direct and ongoing involvement of top management. Value engineering is a tool to improve performance—a tool that management should use, not just prescribe. The result is that each dollar New Mexico invested in value engineering in 1999 produced a savings of $404. Overall, the Department's major investment program realized $247 million in savings.

One of the ways New Mexico measures performance is the "return on investment for value engineering projects," calculated by dividing the amount of money saved from a value engineering study by the cost of doing the study. Improvements to this index also are accompanied by positive, measurable results in other categories, such as "innovative ideas implemented," "average day cost by contract," and "Interstate construction cost per lane mile." Value engineering has had a wide-ranging impact on the overall performance of the Department in delivering products and services to customers.

Changing the Approach

The results-based approach to value engineering is important in the ongoing highway work in New Mexico, which adopted the traditional approach in 1977. The traditional approach included partnership in a design team and commitment to quality as the design team explored cost-saving alternatives. Value engineering was applied to design standards and specifications, high-cost projects and items, construction contracts, and operations.

Initially the role of upper management was to support the idea without direct involvement in practice; however, the results were modest. Then two major changes took place: first, the Department adopted quality management procedures; second, the state undertook a major capital improvement program.

New Mexico had started its largest-ever highway program, $1.2 billion to improve highways and develop economic corridors. The Department was able to support the program by combining innovative financing with value engineering. Top management provided the necessary vision, environment, support, encouragement, and focus.

The Department revised the value engineering practice of the previous two decades and applied new principles to several major projects. New Mexico (NM) 44 provides a good example of how the Department used formal value engineering studies and informally implemented value engineering throughout the highway's design and development.

Innovative Financing

NM 44 is a two-lane, a 146-mile state highway that runs northwest from Bernalillo, north of Albuquerque, to Bloomfield, near the Four Corners region, where Utah, Colorado, Arizona, and New Mexico meet. The road is legendary for severe automobile crashes. Although NM 44 is part of the National Highway System, improvements had been minor. Concerns about public safety, the desire to provide economic development opportunities to the northwestern part of the state, and the poor pavement condition of the highway made the construction of a four-lane NM 44 a priority.

The NM 44 project covers 120 miles of 2 lanes. The Department's initial estimate for this project would have required significant funds from the State Transportation Improvement Program—enough to bring the program to a standstill. Traditional state methods of financing and procurement could have built the project in 5-mile increments but taken 27 years to complete.

New Mexico applied for "innovative financing" under the Intermodal Surface Transportation Efficiency Act of 1991 and as an "innovative contracting" project under Special Experimental Project 14. The application proposed that the state be allowed to pledge future federal-aid highway funds for a term of 18 years to repay bonds.

Following the approval of the applications and concepts, requests for proposals were solicited for the design, construction, management, and warranty of the 120-mile highway facility. The contract was executed in July 1998 with a mandatory completion date of November 2001.

Implementing Recommendations

Value engineering first was applied at the 30 percent design level—that is, when the design was 30 percent complete. The implemented recommendations ranged from minor revisions of construction specifications to major design changes involving horizontal and vertical alignments. The revisions affected the typical roadway section and required modifications to drainage structures and several traffic control elements.

The process was repeated at the 80 percent level. Both studies produced nearly 100 recommendations; 30 became part of the final bid packages. Before value engineering, the construction estimate was $244 million; afterward, the estimate dropped to $212 million.

The corridor was initially developed and designed as eight distinct bid packages. The bids on the first sections were high, and the Department realized that the corridor's completion under a $185 million budget was in jeopardy. Management rejected the bids and undertook a third value engineering effort, directly participating to retain quality while keeping to the budget.

Targeting Risks

Value engineering targeted areas with the greatest potential risk to bidders, including

1. The availability of aggregate material of sufficient quality and quantity;
2. Alternative structures for earth bearing, such as retaining walls, and for drainage; and
3. The ability to achieve economies of scale.

Specifications were modified to allow for material common to the area—for example, recycling asphalt for various uses. Recycled Asphalt Pavement (RAP) could replace or supplement the base course, reducing the amount of virgin crushed aggregate base required. Asphalt concrete (AC) aggregate could be blended with RAP in the lower AC base mixture.

RAP also was suitable for selected backfill behind abutments as well as for tapers, temporary pavement, and turnouts. The state added a contract clause encouraging contractors to propose additional uses of RAP to lower costs. The decision produced savings without affecting quality.

The Department also acquired an alternate aggregate source, including all necessary environmental clearances and air quality permits. The use of the aggregate source was not mandated, but minimized unknown contingencies in the bids. Easing the specifications for the aggregate in the base course construction allowed the use of local aggregate.

Alternate aggregate source material, suggested by value engineering program, played important role in construction on NM 44.

Alternative structures were evaluated for type, availability, and constructibility. The plan had been to minimize right-of-way by constructing retaining walls; value engineering instead recommended geogrid-reinforced fill slopes to allow steeper slopes within the right-of-way. Several other retaining walls also were eliminated. Alternate drainage structures were made available by allowing various material types, including corrugated metal, high-strength plastic, corrugated multiplated pipes, and portland cement concrete.

Value engineering program proposed barrier solutions on NM 44 that reduced cost but maintained quality.

Finally, combining bid packages produced economies of scale. The eight original bid packages became four separate construction contracts.

Assuring Success

The redesign and restructuring of the bid packages took 3.5 months. Top management involvement helped drive the efficiency as well as effectiveness of the value engineering. The last bid package was awarded in February 2000 for a total project cost of $183 million—within the budget.

Value engineering in New Mexico involves management, is results-oriented, and is market-validated. New Mexico's value engineering practice has completed major projects within budget while maintaining a commitment to quality. Management must be involved not only in initiating a value engineering program but in implementing the solutions, ensuring that the same quality of product is provided at the lowest cost.

RUMBLE STRIPS

Finding a Design for Bicycles and Motor Vehicles

DAVE BACHMAN

Dave Bachman is Bicycle and Pedestrian Program Manager, Bureau of Highway Safety and Traffic Engineering, Pennsylvania Department of Transportation, Harrisburg.

The Pennsylvania Department of Transportation (PENNDOT) researched milled rumble strip patterns that are safe and effective for bicyclists as well as motorists on nonfreeway roads—a difficult task, since the needs of each group differ. Although bicyclists want to cross the rumble strip safely and comfortably with minimal vibration, motorists want sufficient vibration and sound to warn that the vehicle is drifting from the travel lane.

Problem

Roads that are open to bicycles—the majority of the highway network—need rumble strips designed to meet the conflicting needs of motorists and bicyclists. Used mainly on urban and rural freeways, rumble strips have reduced crashes and fatalities by 20 to 50 percent.

One reason rumble strips have not been implemented on nonfreeway roads is that they can be uncomfortable for bicyclists to ride over and can cause loss of control of the bicycle—a serious safety issue. Although bicyclists usually travel on the shoulder outside of the rumble strip, they occasionally need to cross it, for example, to make a left turn or to avoid debris.

Solution

Developing a Model

After an assessment of PENNDOT's rumble strip pattern, 25 alternatives were developed and evaluated, and a simulation model was devised and validated. The simulation model indicated that 4-inch-wide (102-mm) grooves would provide the smoothest ride for bicyclists. However, the cutting head on the milling machine used by PENNDOT is a fixed diameter, which means that there is a linear relationship between width and depth of cut. Four-inch cuts would have meant an unacceptably shallow cut. Therefore, 4-inch (102-mm) grooves were not considered further. All of the patterns used the same groove length, between 16 and 17 inches (406 and 432 mm).

Testing the Rumble Strips

The five highest ranked test patterns and PENNDOT's current standard (Table 1) were installed at a test facility for field experiments. Volunteers rode four different bicycle models—mountain, touring, hybrid, and tandem—over the test rumble strip patterns at various speeds and angles (see photo, next page). Vertical acceleration (up and down movement by the bicyclist) and pitch angular acceleration (before and after rocking experienced by

TABLE 1 Rumble Strip Configurations Tested

	Rumble Strip Dimensions, inches (mm)			Performance for Bicyclists	Vehicle Sound Difference dB(A) (Rank)	
Test Pattern	Groove Width	Gap between Grooves	Groove Depth	Composite Score (Rank)	55 mph (88 km/h)	45 mph (72 km/h)
*1	7 (180)	5 (130)	0.5 (13)	0.97 (#6)	23.7 (#1)	11.6 (#2)
2	5 (130)	7 (180)	0.5 (13)	0.50 (#3)	18.5 (#2)	10.0 (#4)
3	5 (130)	7 (180)	0.375 (10)	0.12 (#2)	16.1 (#3)	6.8 (#5)
4	5 (130)	6 (150)	0.5 (13)	0.66 (#5)	16.0 (#4)	15.2 (#1)
5	5 (130)	6 (150)	0.375 (10)	0.50 (#3)	13.9 (#5)	10.9 (#3)
6	5 (130)	7 (180)	0.25 (6.3)	0.003 (#1)	13.0 (#6)	6.3 (#6)

*PENNDOT's current standard.

the bicyclist) data were collected and compared for each pattern. The bicyclists rode on an 8-inch (203-mm) white line over each pattern to measure the effect of the grooves on handling and control, and the researchers recorded the percentage of time spent off the line. The bicyclists rated the comfort and control for each pattern by marking a graphical scale from very uncomfortable to very comfortable.

Rating the Test Patterns

The researchers normalized the scores for each experiment to a scale of 0 (best) to 1 (worst) and averaged the scores to obtain composite scores (Table 1). Test Pattern 1 was clearly the worst from the bicyclist's perspective; conversely, Patterns 6 and 3 were the best and second best. Patterns 2 and 5 had the same composite score, with Pattern 2 doing better on the acceleration tests, and Pattern 5 doing better on the subjective ratings. Pattern 4 did well on the white line test but poorly on the others.

To assess each rumble strip pattern's auditory effect on inattentive or drowsy motorists, the maximum sound level in a vehicle was measured when the vehicle drove over the patterns. The difference between the maximum sound level and the ambient sound level when driving on a smooth pavement was determined (Table 1).

Vertical and pitch angular accelerations also were measured, but were not found useful. Previous research had found that rumble strips producing 4 dB(A) increases above the ambient noise can be readily detected by motorists who are awake (*1*), but there are no data indicating the sound level difference necessary to alert a drowsy motorist.

For higher speed roads, near 55 mph (88 km/h), Pattern 3 was the best balance between the competing needs of motorists and bicyclists. It was the second-best pattern for bicyclists and the third-best for motorists. Pattern 6, the best for bicyclists, was not chosen because it provided the least sound difference to motorists.

For lower speed roads, near 45 mph (72 km/h), Pattern 5—the third-best pattern for both bicyclists and motorists—was recommended. The two best patterns for bicyclists generated less than 7 dB(A) sound above the ambient level, which was not deemed to be sufficient to rouse drowsy motorists.

Application

PENNDOT will install pilot rumble strips designed from Patterns 3 and 5 on nonfreeway routes across Pennsylvania this year. Installation is only on roadways with shoulders at least 6 feet wide, so that there is sufficient room for bicyclists to travel outside of the rumble strip. If these pilot installations are well received by the bicycle community, additional installations will follow.

Volunteer bicyclist tests rumble strip pattern at various speeds and angles.

Benefits

PENNDOT's goal is to reduce crashes and fatalities by 10 percent. Run-off-the-road motor vehicle crashes on nonfreeway facilities make up a significant portion of crashes and fatalities. Although data are not yet available to estimate the reduction in crashes and fatalities due to nonfreeway rumble strips, the success of rumble strips on freeways is a good prediction of performance.

Effectively designed rumble strips also may improve bicyclist safety by providing a buffer between motor vehicles and bicycles and by reducing the number of motor vehicles infringing on the bicyclists' part of the shoulder.

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For more information contact Michael Bonini, Research Division, Pennsylvania Department of Transportation, 400 North Street, 6th Floor, Harrisburg, PA 17120-3789 (telephone 717-772-4664, email mbonini@dot.state.pa.us).

EDITOR'S NOTE: Appreciation is expressed to Ray Derr, Transportation Research Board, for his efforts in developing this article.

Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC 20418 (telephone 202-334-2952, e-mail gjayapra@nas.edu).

Wesley S. C. Lum

Office of Infrastructure Research, California Department of Transportation

"There are many challenges for today's transportation professional—rebuilding the infrastructure for durability and safety while minimizing congestion from construction, improving freight and passenger mobility for all modes, and increasing our ability to serve social and economic needs while being good stewards of the environment," states Wes Lum, Chief, Office of Infrastructure Research, California Department of Transportation (Caltrans). "The role of research is to find ways to meet these challenges."

An expert in transportation operations and a former leader in intelligent transportation systems, Lum has more than 27 years of experience in transportation, including 17 years managing programs and supervising staff in Caltrans headquarters and district offices.

"Researchers should address challenges for the long term as well as the short term and for the world as well as the neighborhood."

An advocate of a team approach, Lum started managing the research program during a major reorganization. He assembled a management team that successfully completed the reorganization and developed new management procedures. Two committees—the Advisory Committee for Research and Development and the Research Program Advisors Council—were created to guide research. The Advisory Committee consists of executives from industry, government, public interest groups, and academia; the Advisors Council comprises mid-level Caltrans managers who provide priority assessments of proposed research.

Notable accomplishments of Caltrans research include a new asphalt concrete specification for a quality control/quality assurance construction program; a major accelerated pavement testing program that is producing results useful in design and construction of long-life pavement; a seismic ground motion program; and three university transportation centers addressing issues in transportation policy, systems effectiveness, freight, infrastructure, and education and career development.

Major new areas of focus are environmental streamlining, nondestructive testing, improved foundations, and minimizing congestion from construction activities. Lum believes that involving the clients, which include Caltrans operating divisions and districts, in researching viable solutions is essential. Most of the projects are partnered and include academia, industry, other state departments of transportation, and the Federal Highway Administration (FHWA).

Before working at Caltrans, Lum was a planning and research engineer in FHWA's California, Texas, Wisconsin, Louisiana, and Washington, D.C., offices. He joined FHWA after a variety of transportation projects with consultants, local government, and academia.

"As a principal research engineer and coauthor of bikeway planning criteria and guidelines, I developed the first modern U.S. design standards," Lum notes. "Along the way, I acquired the enjoyable habit of bicycling to work and have averaged 4,000 miles a year since 1972."

Lum is a member of the American Association of State Highway and Transportation Officials' Research Advisory Committee and chairman of the Western Association of State Highway and Transportation Officials' Research and Advisory Committee. He also is a member of the Institute of Transportation Engineers, the Transportation Research Board (TRB) Committee on Conduct of Research, and the National Cooperative Highway Research Program (NCHRP) Committee 20-5, Synthesis of Information Related to Highway Problems.

Previous TRB experience includes roles on the Committee on Communications, the Committee on Bicycling, and the NCHRP Project Panel on Systems Approach to Evaluating Innovations for Integration into Practice. He also has served as a member of ITS America's Institutional Issues and Environmental Committees.

"Researchers should address challenges for the long term as well as the short term and for the world as well as the neighborhood," states Lum. Leading by example, he has researched, written, and made presentations on earthquake planning and recovery, traffic management, demand management, and bikeway design and operations both nationally and internationally, including Japan, China, Taiwan, and Canada. His publications list is extensive.

"I look forward to the development of a comprehensive and cooperative national transportation research agenda," Lum says. "The transit, rail, environmental, and other interests need to be included. I hope that decision makers at all levels, public and private, can appreciate this national agenda and facilitate the creation of research programs to address our transportation challenges."

Elaine E. Joost

Research and Special Programs Administration, U.S. Department of Transportation

For more than 28 years Elaine E. Joost, Acting Chief Counsel in the Research and Special Programs Administration of the U.S. Department of Transportation, has devoted her career to advancing new ideas in transportation.

Joost entered the field of transportation in 1973 working with researchers at the Volpe National Transportation Systems Center in Cambridge, Massachusetts. She was starting law school, and a recruiter persuaded her that a job in contracts would enhance her training by enabling her to apply her studies daily.

Joost recognized the importance of expressing research objectives and results in clear language and proceeded to incorporate that belief into her work. She advanced safety objectives while serving as Executive Officer at the Materials Transportation Board and drafted administrative opinions on the federal preemption of state and local laws restricting the transportation of high-level radioactive material at RSPA's Office of Chief Counsel.

"Research, like regulation, should offer a solution to a problem. In the case of basic research, it can be an abstruse problem, but even then, the objective is to increase the body of knowledge by which more practical problems can be solved."

"As a contract negotiator, I had to describe what the government would be paying for and how we would know when it was finished," Joost observes. "As a program manager, I've had to persuade policy officials and congressional overseers that a proposed research investment would lead, however indirectly, to a desired goal. And as an attorney, I need to explain how specific research activities fall within the scope of various laws or regulations."

In 1986 Joost moved to the Office of Hazardous Materials Transportation as International Standards Coordinator, representing the United States at meetings of international standards-settings bodies. This position placed Joost in another setting that required an ability to explain technical issues in simple terms.

"Research, like regulation, should offer a solution to a problem," Joost explains. "In the case of basic research, it can be an abstruse problem, but even then, the objective is to increase the body of knowledge by which more practical problems can be solved." Joost notes that excessive focus on the practicality of research investments can overlook the most important potential payoff—the development of creative researchers from whom much can be expected.

Joost takes justifiable pride in her accomplishments in the management of the University Transportation Centers (UTCs) program. Under her leadership, the UTC program expanded in numbers, in level of funding, and in scope. The three main purposes of the program are transportation research, education, and technology transfer.

"Whether trying to increase the number of people in advanced degree programs, or trying to increase their diversity, UTCs need to look beyond eligible undergraduates, or they will just end up in bidding wars for the same students," Joost states. "To increase the numbers going into graduate programs, the number of the students coming through the pipeline has to be increased."

Anticipating the UTC program's reauthorization under the Transportation Efficiency Act for the 21st Century, Joost led her team of UTC specialists to develop a set of quantifiable performance measures for a university grant program. The performance indicators provided a means for evaluating each UTC, not merely in terms of numerical targets, but also with regard to the quality of performance. For the success of this innovative approach, Joost and her team received RSPA's highest award for special achievement.

Joost is active in the Transportation Research Board as Chairman of the Committee on Transportation Education and Training, which she previously served for several years as a member. Under her leadership the committee initiated an annual forum to present and discuss educational content, training tools and techniques, and innovative delivery systems. At the next TRB Annual Meeting, in January 2002, participants in the fourth annual forum will address the design of electronic learning systems.

Computer rendering of a FastShip.

High-Speed Vessels, Portable Ports Offer Military, Commercial Benefits

The Department of Defense (DoD) has adopted a strategy of partnering with the private sector to produce a shared High-Speed Sealift (HSS) fleet and to develop and implement technologies for water transport. The strategy requires DoD to encourage private participation while achieving military performance levels. At the same time, commercial applications of the HSS concept must address environmental concerns and port and transportation network congestion.

Under the "spin on" technologies model, the military and the private sector share risk while jointly developing new technologies for simultaneous commercial and military application. Congress has established the Center for the Commercial Deployment of Transportation Technologies (CCDoTT), a consortium of government, industry, and academic organizations, to

- Streamline freight throughput and logistics for national defense and trade;
- Build on transportation research and development, training, education, and technologies;
- Provide a stable intermodal transportation infrastructure;
- Develop a prototype "agile port" for HSS; and
- Improve cargo tracking, personnel movement, and asset visibility.

Funding has been made available for the HSS–agile port concept, promoting the development of cargo vessels that can cross the ocean at 40 knots or faster, as well as state-of-the-art materials handling technologies, and tagging, tracking, and information management systems. CCDoTT's agile port concept aims to improve freight throughput.

On the private-sector side, David L. Giles, naval architect and entrepreneur, has advanced the FastShip Atlantic concept, which envisions halving the time for transatlantic shipments. The Massachusetts Institute of Technology has conducted studies of the commercial demand, developing a "value creation model" to demonstrate benefits and forecast the types and quantities of commodities most suitable for high-speed water transport.

The FastShip may be efficient for high-value, time-sensitive cargo such as cars, pharmaceuticals, apparel, and consumer goods, but would charge more than conventional freight shippers. Demand for the commodities must be able to justify a new fleet of ships, each of which costs $130 to $150 million to build and $100 million to operate annually. The advantage of the speedy service, however, may be lost when the cargo reaches a port and is transferred to rail or truck to its final destination, meeting bottlenecks in the landside transportation system.

Developed to address the problem of deploying military equipment on rough seas, the Sealift Overhead Rapid Delivery System incorporates the jack-up barge used for offshore drilling. The barge is retrofitted with rotating harbor cranes that have a boom length and capacity to load and unload containers or equipment from the far side of an HSS vessel. The barge deck has a conveyor that queues and stages containers and equipment for loading.

The barge hull contains the piles for mooring vessels as well as the pile drivers, trolley girders, and other equipment necessary to construct a "portable port" in any location. The portable port facility can off-load cargo onto trucks or onto light or freight rail.

Deployment of a portable port has less impact on the environment than the construction and maintenance of traditional port infrastructure—environmental disturbance is limited to the piles, which are in place only temporarily. In addition, the opportunity to move waterborne freight outside the traditional gates of a port may affect urban development and activity and also may have economic and development impacts on rural areas.

Communication is needed to ensure time-sensitive and location-efficient intermodal connectivity of the HSS vessels with portable port operations and with the freight-receiving trucks or rail. Attempts to "tag and track" vehicles and containers are under way in both the private and military sectors.

The Puget Sound region, for example, has deployed a traffic information system, Smart Trek, to provide timely information for travelers using cars, trucks, ferries, and buses; shorten emergency and incident response times; and manage traffic. Real-time information is transmitted via the Internet and cable television, with plans for using in-vehicle and handheld devices. TransCore is conducting a field test of Global Positioning System technology on trucks, providing real-time information on vehicle location to trucking and drayage firms.

DoD has developed the Transportation Automated Measurement System, which measures equipment at its origin, moves the equipment to a staging area, and scans it automatically at the port to record receipt and final shipment. Data on the dimensions and weight are transmitted to a DoD database, used to produce an optimal stow plan and to track the assets.

The "just in time" and "just at the right time" inventory management strategy of HSS, portable ports, and advanced communication systems may generate a larger market than waterborne, rapid freight movement alone. Instead of increasing congestion at ports, the HSS operations strategy can move intermodal activities away from congestion and supply accurate time and location data for shipments.

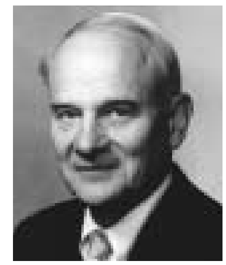
Adapted from a presentation by Catherine Lawson (telephone 518-442-4775, e-mail lawsonc@albany.edu), State University of New York at Albany, to the 42nd Annual Research and Policy Forum, November 2000, Annapolis, Maryland.

Intermodal Transportation Database Boots Up

The U.S. Department of Transportation's (DOT's) Bureau of Transportation Statistics (BTS) has released a beta-test version of its Intermodal Transportation Data Base (ITDB), which collects a wide range of transportation data. ITDB draws from databases compiled by the operating administrations within U.S. DOT as well as other federal agencies, such as the U.S. Census Bureau, the Bureau of Labor Statistics, and several nonfederal research institutions and associations. The aim is to provide "one-stop shopping" for transportation data and ultimately to improve transportation through more effective and efficient research.

The ITDB databases and links allow users to explore transportation issues and find answers to many transportation-related questions. The project will grow as more data sets become available and geographic information systems tools are added. Still in development is a prebuilt query feature for quick retrieval of information or creating customized queries. The home page address is www.bts.gov; users can send comments and suggestions to answers@bts.gov.

Wulf Re-Elected Engineering Academy President



William A. Wulf

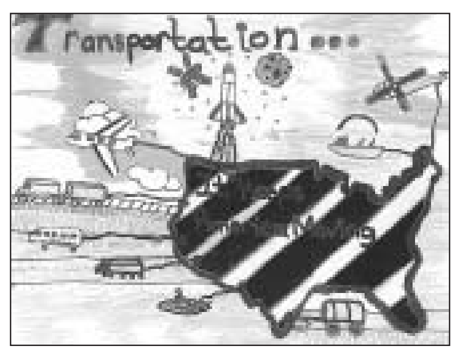
William A. Wulf has been re-elected to serve a six-year term as president of the National Academy of Engineering (NAE). President of the National Academies unit since 1997, Wulf is on leave from the University of Virginia, Charlottesville, where he is a professor and holds the AT&T Chair in Engineering and Applied Sciences.

Wulf's distinguished career includes terms as assistant director of the National Science Foundation; chair and chief executive officer of Tartan Laboratories Inc., Pittsburgh; and professor of computer science at Carnegie Mellon University, Pittsburgh. As NAE president, Wulf is vice chair of the National Research Council, the principal operating arm of the National Academy of Sciences, NAE, and the Institute of Medicine.

Under Wulf's leadership, NAE has launched initiatives in such areas as public understanding of engineering, technological literacy, engineering education, diversity of the engineering workforce, earth systems engineering, and planning for extremely large urban areas—or megacities—in developing countries and regions prone to natural disasters.

Art as a Vehicle: Student Goes Far with Poster

Sean Goldinger, a fifth-grader at Hillside Elementary School, New Cumberland, Pennsylvania, won first place in the National Transportation Week poster contest, celebrating the role of transportation in the life of Americans. The theme was "Transportation…It Keeps America Moving." Goldinger received a savings bond and plaque and traveled to Capitol Hill, where he met Pennsylvania Congressman Todd R. Platts and U.S. Secretary of Transportation Norman Y. Mineta.



First-place drawing in 2001 National Transportation Week's Poster Contest.

"We are fortunate in this country to have a transportation system that fosters economic growth, quality of life, and virtually unlimited access to goods, services, and destinations," Mineta said. "National Transportation Week affords us an excellent opportunity to celebrate our achievements and work together across modes to look at our future."

Established by a Congressional joint resolution in 1962, National Transportation Week includes National Defense Transportation Day, the third Friday in May. The occasion promotes greater awareness of the importance of transportation and focuses on transportation-related career opportunities for young people.

For further information contact Maggie Glesner, National Transportation Week (telephone 703-235-0519).

Awards Boost Environmental, Educational Programs

In April U.S. Transportation Secretary Mineta announced the winners of the Federal Highway Administration's (FHWA's) 2001 Environmental Excellence Awards. The Secretary also noted awards to historically black colleges and additional sites for FHWA's National Summer Transportation Institute (NSTI).

Environmental Excellence

This year's Environmental Excellence Award-winning projects range from the ambitious streamlining of environmental reviews in Pennsylvania to an innovative landscape-design tool in Minnesota and a unique bicycle-pedestrian trail in Puerto Rico.

"These public-private efforts are good examples of environmental stewardship and successful partnering," said FHWA Deputy Executive Director Vincent Schimmoller. "They inspire us to act responsibly, protecting and enhancing the environment without compromising mobility or causing financial hardship."

The 2001 Environmental Excellence Award recipients are from California, Florida, Minnesota, New Jersey, New York, North Carolina, Pennsylvania, West Virginia, and Puerto Rico. FHWA has presented the awards biennially since 1995. For a complete list of the 2001 winners and a description of the projects, visit www.fhwa.dot.gov/pressroom/fhwa0117.htm.

National Summer Transportation Institutes

FHWA recognized 13 primarily Historically Black Colleges and Universities (HBUCs) with 18 different awards and added 6 sites to the 34 NSTI host sites.

"National Summer Transportation Institutes are fine examples of how partnerships can be forged to show youth the benefits of studying and applying advanced math, sciences, and technology skills," said Mineta.

NTSI is one of several U.S. DOT educational initiatives to prepare students for careers in transportation. Host sites include HBUCs and other Minority Institutions of Higher Education across the country, with South Carolina State University serving as NSTI's national resource center.

The six schools added to the program are Central State University, Ohio; Denmark Technical College, South Carolina; Langston University, Oklahoma; Southwestern Indian Polytechnic Institute, New Mexico; University of Puerto Rico; and White Earth Tribal and Community College, Minnesota.

For a complete list of the awards and more information about NSTI, visit www.nrc.scsu.edu.

Boston Project Bridges the Gap Between Form and Function

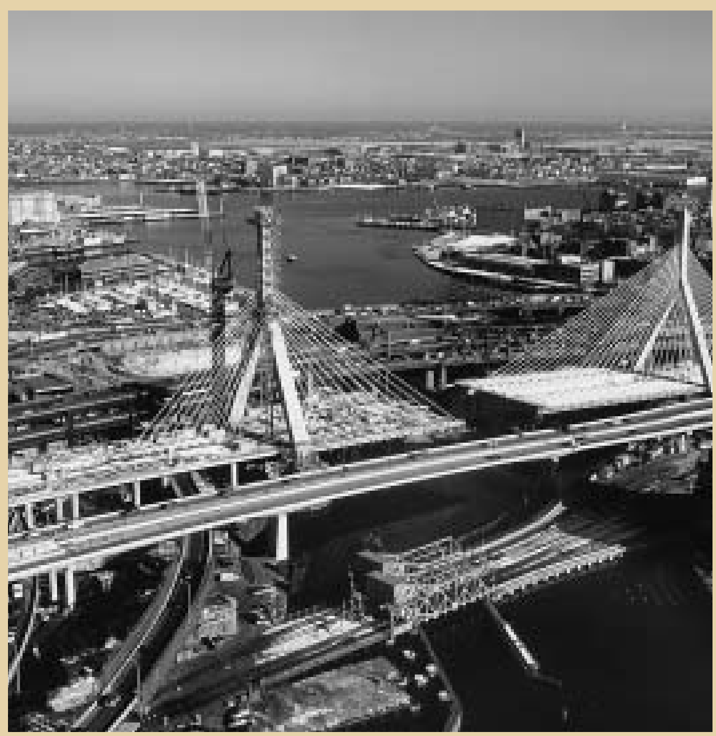
The world's widest cable-stayed bridge is spanning the Charles River, connecting Boston to Cambridge, Massachusetts. Two inverted Y-shaped towers support the 1,457-foot-long bridge; eight lanes pass through the legs of the towers, while two additional lanes are cantilevered on the east side of the bridge—an asymmetrical feature is unusual in bridge design.

Scheduled to open in 2002, the bridge is 183 feet wide and is the only cable-stayed bridge in America with a single plane of stays in the back span and a dual plane of stays in the main span. The hybrid design of concrete for the back span and steel for the main span is another first in the United States. The engineering coup also reflects a trend of increased community interest and involvement in infrastructure planning.

"Cities are trying to build bridges that carry more traffic while adding to the identity of the community, " said Jim Cooper, FHWA's director of bridge technology. "Residents are having much more say about the design process."

The bridge design also includes something for marine life—a series of semicircles every 20 feet along the edge of the roadbed allow sunlight to break up the shadow cast on the river, minimizing disturbance to the indigenous fish known as alewife.

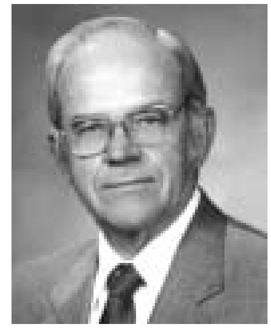
For further information contact Bradley Touchstone, Figg Bridge Engineers, Inc. (telephone 1-800-358-3444, e-mail btouchstone@figgbridge.com).



Construction on widest cable-stayed bridge, spanning Charles River, Boston.

IN MEMORIAM

Charley V. Wootan, 1926–2001



Charley V. Wootan

Charley V. Wootan, director of the Texas Transportation Institute (TTI) from 1976 to 1993 and director emeritus since his retirement, died in March. He is credited with building TTI into the largest university-affiliated transportation research center in the United States.

Past Chairman of the TRB Executive Committee and a mainstay of TRB activities for nearly 40 years, Wootan was widely respected and recognized as a leader and a mentor of leaders in the field of transportation and as a contributor to transportation advancements and safety improvements.

"Charley was remarkable for his generous spirit, quiet confidence, and good humor," TRB Executive Director Robert E. Skinner, Jr., noted. "When he took on an assignment for TRB, we knew we were fortunate."

"Even though Charley was busy and he had already done it all, he was always willing to take on new assignments and to show us, once again, what leadership is all about," said Cooperative Research Programs Director Robert J. Reilly, speaking as TRB's representative at the memorial service for Wootan.

After serving in the U.S. Marine Corps in the South Pacific and China theaters during World War II, Wootan earned bachelor's, master's, and doctoral degrees in agricultural economics at Texas A&M University. He spent almost his entire career at TTI, starting as a research assistant in 1951 and advancing as project leader, Advisory Committee director, head of the Transportation Economics and Planning Division, associate director and research economist, professor of economics, director, and director emeritus. Wootan contributed to many significant reports and papers and lectured extensively on such topics as "Social and Economic Aspects of Highways," "The Role of Research Centers in Transportation Research," and "Energy Policy Implications on Transportation."

Before and after his chairmanship of the TRB Executive Committee in 1980, Wootan served terms as chairman of the Division A (Technical Activities) Council, from 1979 to 1980 and from 1986 to 1989. He chaired the TRB Committee for a Study To Identify Measures That May Improve the Safety of School Bus Transportation (1987-1989) as well as the National Cooperative Highway Research Program (NCHRP) project panel that developed a Strategic Plan for the NCHRP (1993-1994). A member of the Research and Technology Coordinating Committee (Highways) from 1991 to 1996, he also chaired Division A Group Councils and contributed leadership and insights to more than a dozen other TRB committees and task forces.

In 1984 Wootan received TRB's W. N. Carey Distinguished Service Award for outstanding service to transportation research and the Board. In 1987, the American Association of State Highway and Transportation Officials and the American Road and Transportation Builders Association joined TRB in presenting Wootan with the George S. Bartlett Award for outstanding contributions to transportation progress.

TTI has established a memorial fund jointly honoring Wootan and his predecessor as TTI director, Charles J. "Jack" Keese; for more information, see http://tti.tamu.edu/keese_wootan.stm.

Malcom P. McLean, 1914–2001

Malcom McLean, who died on May 25, did not participate in TRB activities and probably did not think of himself as a researcher. But, he was an innovator. Known as "The Father of Containerization," McLean's idea for packaging and shipping freight transformed the shipping industry. Currently, 90 percent of the world's merchandise is transported in container units. The economic effect has been significant—ports have grown, new technology has developed, and shipping has become faster, more efficient, and cheaper.

In 1934 McLean, with his brother and sister, founded McLean Trucking Company, which by the early 1950s had become the second largest trucking company in the United States; it was the first to use diesel tractors. His idea for containerization came about when he was making a truck delivery to a port and waited while dockworkers moved each piece of cargo individually. How could the process be speeded up? His answer—put the whole truck body on the ship.

After selling his share of McLean Trucking and purchasing Pan-Atlantic Steamship Company (later renamed Sea-Land Service) in 1955, McLean put his containerization idea into practice.

R. J. Reynolds bought Sea-Land Service in 1969, and McLean became a member of the board of directors. By 1978 he resigned and bought United States Lines, which he ran until its bankruptcy in 1986. In 1992, at the age of 78, McLean founded Trailer Bridge, which continues to operate trucks and barges between the United States and Puerto Rico.

McLean received the International Maritime Hall of Fame's "Man of the Century" award and American Heritage Magazine's 1995 citation as one of ten outstanding innovators over the previous 40 years.

State representatives hear about light sources and reflectivity on a tour of the Turner-Fairbank Photometric and Visibility Laboratory.

Representatives State Progress, Make Recommendations

Transportation Research Board (TRB) state representatives from more than 40 state departments of transportation (DOTs) convened May 9–11, 2001, in Washington, D.C., to share information and provide advice on a range of activities. TRB established the state representatives program in 1924 as a vital link to its state DOT constituency.

After a briefing on current TRB activities, the representatives participated in a series of discussion groups and generated recommendations that TRB

◆ Enhance communications with state DOTs,
◆ Optimize state visits by staff,
◆ Develop and deliver useful and timely publications to state DOTs,
◆ Ensure that committees address issues of most concern to state DOTs, and
◆ Identify new TRB products and services valuable to state DOTs.

These recommendations are under consideration as part of the update of the TRB strategic plan and the TRB Technical Activities Division Quality Improvement Program.

The group also documented and discussed several innovative research programs and projects under way at state DOTs, including the SMARTRAQ Research Program (Georgia), the Alliance for Transportation Research and Applied Development (Kansas), Project Management and Progress Tracking System (New Jersey), Invitation to Quality Contracting Tool (Penn-sylvania), and Forging Partnerships and Cooperative Programs (Wisconsin).

On the final day of the workshop, the group heard updates on the research programs of several federal agencies, including the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration, the Federal Aviation Administration, the Federal Railroad Administration, and the U.S. Army Corps of Engineers. The meeting concluded with a tour of FHWA's Turner-Fairbank Research Center laboratories.

The next biennial meeting of the TRB state representatives will take place in 2003.

For further information contact Mark Norman, TRB (telephone 202-334-2941, e-mail mnorman@nas.edu).

At the Turner-Fairbank Structural Laboratory, state representatives observe ultrahigh-performance concrete beams being tested for bridge construction.

Measuring Waterways Capacity

Waterways users and managers are increasingly concerned about safety, environmental protection, system efficiency, and effective management. Factors that affect the capacity of waterways and channels include types and mix of vessels, access, and impacts on a variety of users.

Many ports and waterways face significant increases in commercial shipping, passenger ferry operations, larger ships, and recreational use, as well as other changes. The general public is concerned about maintaining healthy coastal ecosystems and protecting environmental quality.

The capacity and condition of the U.S. waterway system to handle a diversity of uses and growth safely and efficiently requires a national perspective. To address questions of theoretical and practical approaches to measuring waterways capacity, TRB's Marine Board hosted a seminar in April, convening a group of key public and private officials to present and discuss major issues.

PHOTO: BILL DRYER

Containership and ondock rail at the Port of Long Beach, California. The marine transportation system faces both waterside and landside capacity challenges as size of vessels, mix of users, and volume of traffic continue to grow.

Establishing a rational approach to measuring the capacity of the nation's waterways might provide a tool for improving management practices and setting priorities for competing uses. Waterway capacity reports comparable to the periodic condition and performance reports submitted to Congress for highways, bridges, and the national aviation system could serve as the basis for assessing demand and needed changes to such features as channel design, areas for specific functions, and traffic management. Alternatively, a measurement tool might establish needs for future investments in waterways infrastructure by the government and private sector.

A viable measurement scheme would need to meet the test of practical application. Questions addressed at the TRB seminar included:

◆ What measures might be used to determine and assess the carrying capacity of specific waterways in terms of the various segments of the marine transportation system and other users?

◆ If capacity can be established, are there adequate management tools available to make sure use doesn't exceed capacity?

◆ What techniques could be devised to determine and measure congestion in waterways, considering the complexities, volume, and mixture of traffic?

◆ What measurements could be established to determine progress in improving safety, efficiency, mobility, and other important factors in waterways and ports, and how do these factors affect capacity?

◆ How can waterways managers gauge the success or failure of actions to relieve congestion or increase capacity or both? For example, can the impact of traffic management schemes or other navigation improvements on the total capacity of a waterway be measured?

◆ Can the measurement of waterways capacity provide insights into the nation's maritime infrastructure condition, performance, and future needs and help justify program needs and resources?

Presentation materials and a transcript of the plenary session are posted on the Marine Board's webpage, which can be found via the TRB website (www.TRB.org).

For further information contact Joedy Cambridge, TRB (telephone 202-334-3205, e-mail jcambrid@nas.edu).

Workshop Addresses Future of Naval Engineering

Charged with maintaining a robust capability in naval engineering, the Office of Naval Research (ONR) is committed to a strong science and technology base so that the education, research, and engineering communities can provide the talent, ideas, and products needed for today's and tomorrow's fleet.

The Military Sealift Command's Large Medium Speed Roll-On–Roll-Off Vessel, shown here berthed in Newport News, Virginia, is one example of technologically-advanced types of vessels designed and built for U.S. Navy.

In May the TRB Marine Board hosted a planning workshop to explore opportunities and initiatives to attract people to the naval engineering community—in research, to support innovation; in engineering, to develop advanced naval vehicles; in production, to enhance efficient acquisitions; and in the application of commercial approaches.

The U.S. Navy relies on a focused research community to advance the state of the art, generate an adequate pipeline of new scientists and engineers in naval engineering disciplines, and provide operational forces with the science and technology to enhance fleet performance. Naval engineering disciplines include all arts and sciences applied in the research, development, design, construction, operation, maintenance, and logistics support of

- Surface ships, submarines, and marine craft;
- Naval maritime auxiliaries;
- Combat systems including command and control, electronics, and ordinance systems; and
- Ocean structures and associated shore facilities used by naval and other military forces and civilian maritime organizations for the defense and well-being of the nation.

The long-range objective of the initiatives discussed in the workshop is to develop the people, infrastructure, and knowledge base that will produce and enable creative ship designers and ship researchers for the future.

For further information contact Joedy Cambridge, TRB (telephone 202-334-3205, e-mail jcambrid@nas.edu).

TRB Online News

The first edition of the online TRB Technical Activities Leadership Newsletter was distributed electronically to Technical Activities Division (Division A) Group Council members, section leaders, standing committee chairs, state representatives, federal sponsors, and university and transit representatives in May. The monthly newsletter provides updates on the latest TRB news, including announcements of new publications, reports, and meetings and conferences sorted by technical area. In addition, the newsletter report offers general TRB, Division A, and Annual Meeting news. The newsletters will be archived on the TRB website (www.TRB.org) for future reference.

For further information contact Mark Norman, TRB (telephone 202-334-2941, e-mail mnorman@ nas.edu).

Aviation Gridlock: How Can It Be Alleviated?

As pressure increases on the national airspace system, including airports and supporting facilities and services, it is important that all elements of the system—commercial airlines; passengers; local, state, and federal governments; business and industry—understand and work together to maintain the world's safest and most efficient aviation system. To address this need, the Federal Aviation Administration (FAA) and TRB launched a series of three one-day seminars on Aviation Gridlock: Understanding the Options and Seeking Solutions, with sessions in February, April, and May 2001.

The seminars aimed to enhance public understanding of the issues, organizations, and possible solutions to air transportation problems as the nation enters a period of increased demand, limited capacity, and inclement weather patterns traditionally associated with summer. The topics addressed airport capacity and demand management, airport capacity and infrastructure, and weather and technology.

Phase I of the seminar series focused on demand management by examining three areas. The first was airport delay and congestion, addressed by looking at the anatomy of a delay, airline scheduling, and the customer's perspective. The second set of presentations reviewed administrative and market demand management options. The third and final group of

presentations covered the operational, legal, and political challenges in adopting new demand management strategies.

The second part of the series addressed airport capacity through improvements in infrastructure. Panels addressed the topics of future needs and airfield capacity—including a description of the current system as well as economic and consumer impacts, the current approach to airfield capacity development, and suggestions to expand airfield capacity.

Thunderstorms, snow, ice, tornadoes, high winds and a variety of other weather conditions create delays, safety problems, and major inconveniences for airline passengers across the country. The third part of the Aviation Gridlock series took a closer look at weather, starting with a breakdown of a weather delay and its effect on airline operations, safety, and scheduling.

The session also looked at the timely communication of weather-related information from the perspectives of a controller, a dispatcher, and a representative of the FAA Command Center. Also discussed were technological advances that can aid in forecasting severe weather quickly and accurately and in relaying that information to the airlines.

"For us in aviation—and those of you who are pilots and those of you from the airlines know this very well—weather is fundamental to our life," said FAA Administrator Jane H. Garvey who introduced the seminar. "There has to be a healthy respect for the weather. We need to plan for it and certainly we need to avoid it when it is dangerous."

For further information contact Joe Breen, TRB (telephone 202-334-3206, e-mail jbreen@nas.edu).

Cooperative Research Programs News

Corrosion-Damaged Bridge Elements: Maintain, Repair, or Replace?

Corrosion-induced deterioration of reinforced concrete bridge superstructure elements is a common and costly problem in the United States. A rational decision to maintain, repair, or replace deteriorated elements must take into account the condition of the element, the extent of deterioration, the expected remaining service life, and the impact of alternative maintenance and repair options on the service life.

Available publications do not provide reliable procedures for evaluating the condition of corrosion-damaged elements or approaches for comparing the effectiveness of maintenance and repair alternatives. Research is needed to identify or develop procedures for assessing the condition of corrosion-damaged bridge elements, estimating the expected remaining service life, and determining the effects of maintenance and repair options. This information can be incorporated into the selection of the optimal repair strategy.

Concorr, Inc. of Ashburn, Virginia, has been awarded a $350,000, 30-month contract (NCHRP Project 18–06A, FY 1998) to develop a manual of step-by-step procedures for assessing the condition of reinforced concrete bridge superstructure elements subjected to corrosion-induced deterioration, predicting the elements' remaining service life, and quantifying the service life extension expected from alternative maintenance and repair options. The research will focus on concrete bridge superstructure elements reinforced only with epoxy-coated or "black" steel or both; it will not deal with prestressed concrete elements or with other types of reinforcing steel.

For further information contact Amir N. Hanna, TRB (telephone 202-334-1892, e-mail ahanna@nas.edu).

CALENDAR

TRB Meetings

2001

August

10 Forum on Pavement Performance Data Analysis
Seattle, Washington
Robert Raab

11–14 5th International Conference on Managing Pavements*
Seattle, Washington
Bill Dearasaugh

12–14 Bus Rapid Transit Conference (BRT)
Pittsburgh, Pennsylvania
Peter Shaw

14–17 International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*
Aspen, Colorado
Richard Pain

September

9–13 7th International Conference on Concrete Pavements*
Orlando, Florida
Frederick Hejl

12–14 12th International Workshop on Future Aviation Activities
Washington, D.C.
Joseph Breen

19–21 Traffic Safety on Three Continents*
Moscow, Russia
Richard Pain

23–25 Conference on Transportation and Economic Development
Portland, Oregon
Jon Williams

23–25 4th National Transportation Asset Management Workshop*
Madison, Wisconsin
Jon Williams

24–28 International Conference on Ecology and Transportation
Keystone, Colorado
Jon Williams

October

2–5 2nd World Steel Bridge Symposium*
Chicago, Illinois
Bill Dearasaugh

28–31 Northeast Community Impact Assessment Workshop
New Jersey
Jon Williams

29–30 New York City Bridge Conference 2001*
New York City, New York
Bill Dearasaugh

November

4–7 1st Human-Centered Transportation Simulation Conference*
Iowa City, Iowa
Richard Pain

7–9 3rd International Large Truck and Bus Safety Symposium*
Knoxville, Tennessee
Richard Pain

14–16 Asphalt Paving Symposium*
Austin, Texas
Bill Dearasaugh

14–16 Biennial Marine Transportation System Research & Technology Coordination Conference
Washington, D.C.
Joedy Cambridge

15–17 Workshop on Intersection Safety*
Milwaukee, Wisconsin
Richard Cunard

December

5–7 Southeast Community Impact Assessment Workshop*
Raleigh, North Carolina
Jon Williams

10–12 Remote Sensing for Transportation Conference
Washington, D.C.
Thomas Palmerlee

2002

January

12 Forum on Pavement Performance Data Analysis
Washington, D.C.
Robert Raab

13–17 TRB 81st Annual Meeting (paper submissions accepted from May 1 to August 1)
Washington, D.C.
Mark Norman

13 35th Annual Human Factors in Transportation Workshop
Washington, D.C.
Richard Pain

13 Doctoral Student Research in Transportation Geotechnics
Washington, D.C.
G. P. Jayaprakash

Additional information on TRB conferences and workshops, including calls for abstracts, registration and hotel information, lists of cosponsors, and links to conference websites, is available online (www4.TRB.org/trb/calendar.nsf). Registration and hotel information usually is available 2 to 3 months in advance. For information, contact the individual listed at 202-334-2934 (fax 202-334-2003; e-mail lkarson@nas.edu).

*TRB is cosponsor of the meeting.

13 Workshop on Geotechnical Instrumentation for Monitoring Performance
Washington, D.C.
G. P. Jayaprakash

13 Incident Management
Washington, D.C.
Richard Cunard

13 Transit Signal Priority
Washington, D.C.
Richard Cunard

13 The Truth About the Costs of ITS: A TRB Workshop
Washington, D.C.
Kimberly Fisher

13 Workshop on Concrete Curing: Basic Principles, Practical Experiences, and Innovations
Washington, D.C.
Frederick Hejl

13 Workshop on Disadvantaged Business Regulations Administrative and Procedural Updates
Washington, D.C.
Frederick Hejl

13 Workshop on Perpetual Asphalt Pavements
Washington, D.C.
Frederick Hejl

13 Workshop on Track Maintenance Planning and Railroad Infrastructure Maintenance Management
Washington, D.C.
Elaine King

13 Workshop on Use of Lithium To Mitigate Alkali-Silica Reactivity
Washington, D.C.
Frederick Hejl

February

14–16 International Deep Foundations Congress*
Orlando, Florida
G. P. Jayaprakash and Carol Bowers

20–21 Getting Active at Passive Rail-Highway Crossings*
Melbourne, Australia
Richard Cunard

April

14–18 ASCE 2nd International Conference on Urban Public Transportation Systems*
Alexandria, Virginia
Peter Shaw

21–25 3-D Visualization in Transportation
Salt Lake City, Utah
Richard Pain

25–26 ASCE Context Sensitive Highway Design Workshop*
San Antonio, Texas
Bill Dearasaugh

28–May 1 3rd National Seismic Conference and Workshop on Bridges and Highways*
Portland, Oregon
Bill Dearasaugh

May

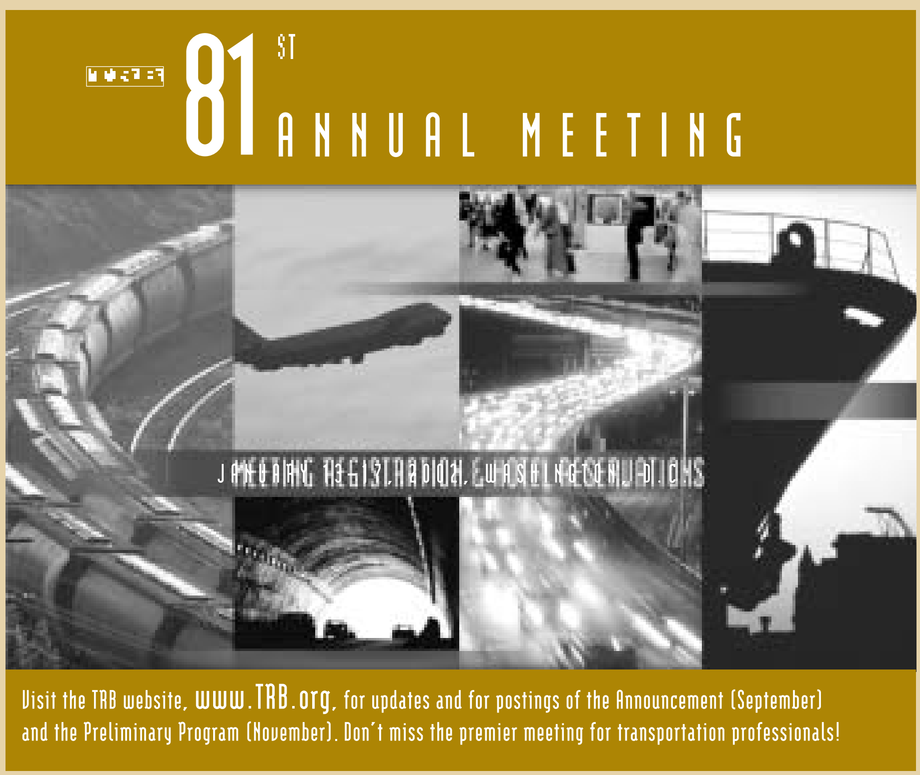
12–16 North American Travel Monitoring Exposition and Conference*
Orlando, Florida
Thomas Palmerlee

June

1–4 Visibility and Simulation Symposium
Iowa City, Iowa
Richard Cunard

23–26 5th National Access Management Conference
Austin, Texas
Kimberly Fisher

26–29 Highway Capacity and Quality of Service Committee 2002 Midyear Meeting and Conference
Milwaukee, Wisconsin
Richard Cunard



TRB Publications

Elastomeric Bridge Bearings: Recommended Test Methods
NCHRP Report 449
This report from a project to develop performance-related specifications for elastomeric bridge bearings recommends specifications and presents three new test methods for evaluating essential properties of elastomeric bearings—creep, shear modulus, and compressive strain. Also provided are recommended specifications for the acceptance testing of elastomeric bearings.

2001; 117 pp.; TRB affiliates, $25.50; TRB nonaffiliates, $34. Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); materials and construction (IIIB).

Transportation Research Thesaurus and User's Guide
NCHRP Report 450
The development and structure of the *Transportation Research Thesaurus*—included with the report as a CD-ROM (*CRP CD-ROM 6*)—is described. The text also covers the use of the thesaurus in developing index terms for documents and publications. The volume provides information for maintaining the thesaurus and serves as a guide for readers who plan to use the thesaurus for indexing. TRB has adopted the thesaurus as the official list for selecting Transportation Research Information Services (TRIS) indexing terms or descriptors.

2001; 60 pp. + CD-ROM; TRB affiliates, $21; nonaffiliates, $28. Subscriber category: none (special distribution).

Innovative Practices To Reduce Delivery Time for Right-of-Way in Project Development
NCHRP Synthesis 292
In recent years the project development process has become more complex, time consuming, and costly, with increasing emphasis on social, economic, and environmental concerns. State transportation agencies are searching for methods to make the process more efficient and effective. The right-of-way function, a critical element in project development, can make the process more efficient. This synthesis helps transportation agencies identify practices and organizational structures that promote the efficient delivery of the right-of-way necessary for project construction. Successful strategies agencies have employed to accelerate the process are reported.

2000; 73 pp.; TRB affiliates, $21.00; nonaffiliates, $28. Subscriber category: planning and administration (IA).

Reducing and Mitigating Impacts of Lane Occupancy During Construction and Maintenance
NCHRP Synthesis 293
The safe and efficient flow of traffic approaching and traveling through construction work zones is a major concern to highway users and those involved in maintaining and improving roadways. The traveling public demands increased mobility, but is less tolerant of delays and inconvenience as the result of congestion, particularly caused by construction and maintenance. Some delays also may affect commerce. This synthesis provides a way to identify and assess the techniques, methods, and processes that reduce lane occupancy and its impact during construction and maintenance. It identifies the types of facilities and projects best suited for the techniques and presents current methods to evaluate lane occupancy reductions.

2000; 60 pp.; TRB affiliates, $20.25; nonaffiliates, $27. Subscriber categories: planning and administration (IA); materials and construction (IIIB); maintenance (IIIC).

Communicating with Persons with Disabilities in a Multimodal Transit Environment
TCRP Synthesis 37
Travelers with disabilities, including sensory, vision, hearing, and cognitive impairments, need alternative methods for accessing and processing transit information. Appropriate attention to information and communication technologies related to planning, customer service, marketing, and training can improve the experience for all who use public transportation. This synthesis defines the needs of those with sensory impairments who use transit; describes North American use of information and communication technologies, as well as operations, implementation, and human factors issues; and presents practical and innovative solutions. Recommendations for alternatives and for future research are offered. This report is also available in HTML and PDF formats on the TRB website.

2001; 48 pp.; TRB affiliates, $19.50; nonaffiliates, $26. Subscriber category: public transit (VI).

High-Occupancy Vehicle Systems and Demand Management 2000
Transportation Research Record 1711
The effectiveness and the cost-effectiveness of high-occupancy vehicle (HOV) lanes, as well HOV policy issues, success factors, and user lifestyles are some of the subjects of new findings in this volume. Customized trip reduction and effective transportation demand management receive attention in other papers.

2000; 62 pp.; TRB affiliates, $21; nonaffiliates, $28. Subscriber category: highway operations, capacity, and traffic control (IVA).

Construction 2000
Transportation Research Record 1712
Part 1 treats topics in portland cement concrete pavement—top-down cracking in fast-setting hydraulic cement concrete and pavement rehabilitation in urban corridors. Part 2 deals with asphalt concrete pavement, Superpave quality control and quality assurance, notched-wedge longitudinal joint construction, overlay ride quality, construction-related temperature differentials, and more. Part 3, on management of quality assurance, covers quality measures, pay schedules, and end-result specifications. Bridges and structures are discussed in Part 4, including rapid bridge deck replacement, cast-in-place segmental construction, and more. Part 5, construction management, examines construction inspection checklists, contract time determination, and partnering in design-build projects.

2000; 211 pp.; TRB affiliates, $45; nonaffiliates, $60. Subscriber category: materials and construction (IIIB).

Railroad Track Engineering and Maintenance; Passenger Rail Planning and Operations
Transportation Research Record 1713
The technology of asphalt trackbeds, remedial methods to correct track substructure instability, sleeper replacement strategies, rail track maintenance planning, and an Austrian track testing and recording car are the topics examined relating to railroad tracks. Tools for passenger rail environmental analysis and boarding-aid devices for disabled passengers on heavy rail complete the volume.

2000; 55 pp.; TRB affiliates, $21; nonaffiliates, $28. Subscriber category: rail (VII).

Recycled and Secondary Materials, Soil Remediation, and In Situ Testing
Transportation Research Record 1714
Researchers discuss slope stabilization with plastic pins, evaluate excess foundry system sands for use as subbase material, examine laboratory tests on cement kiln dust as a soil stabilizer, and investigate liquefiable gravels. A critical review of coupled flow theories for clay barriers is included as well as a paper on the influence of soil suction and environmental factors on drying characteristics of granular subgrade soils.

2000; 106 pp.; TRB affiliates, $24; nonaffiliates, $32. Subscriber category: soils, geology, and foundations (IIIA).

Work Zone Safety; Pavement Marking Retroreflectivity
Transportation Research Record 1715
Papers highlight discussion on removable rumble strips, special flashing warning lights for service vehicles, pavement markings, and work zone fine laws. Also included are safety models, risk analysis techniques, and analyses of fatal crashes.

2000; 70 pp.; TRB affiliates, $22.50; nonaffiliates, $30. Subscriber category: maintenance (IIIC).

Pavement Assessment and Testing
Transportation Research Record 1716
The collection examines the effect of moisture on modulus values of base and subgrade materials, the curvilinear behavior of base layer moduli from deflection and seismic methods, a full-scale study of the rutting of thin pavements, the performance of Superpave mixtures under accelerated load testing, and the super-accelerated testing of flexible pavement with a stationary dynamic deflectometer.

2000; 153 pp.; TRB affiliates, $32.25; nonaffiliates, $43. Subscriber category: pavement design, management, and performance (IIB).

Highway and Traffic Safety: Crash Data, Analysis Tools, and Statistical Methods
Transportation Research Record 1717
Topics include crash- and injury-outcome multipliers, injury effects of rollovers and events sequence in single-vehicle crashes, heuristic vehicle classification using inductive signatures on freeways, and accident prediction models. Also explored are Norway's "Speak Out!" campaign, Mexico's relational accident database management system for federal roads, and accident-reduction measures on California's state highways.

2000; 136 pp.; TRB affiliates, $32.25; nonaffiliates, $43. Subscriber category: safety and human performance (IVB).

Activity Pattern Analysis and Exploration: Travel Behavior Analysis and Modeling
Transportation Research Record 1718
This volume addresses stochastic frontier models of prism vertices, the activity-travel patterns of nonworkers in the San Francisco Bay area, an evaluation of the effects of traveler and trip characteristics on trip chaining, and a preliminary analysis of period effects and cohort effects in life cycles.

2000; 106 pp.; TRB affiliates, $24; nonaffiliates, $32. Subscriber category: planning and administration (IA).

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