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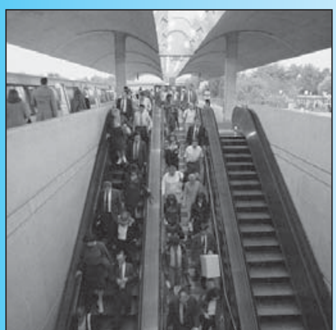

Cover: The new *Transit Capacity and Quality of Service Manual* assists planners in setting transit service goals for a community. Shown here, Washington, D.C.-area commuters depart from the Shady Grove Metrorail station in Derwood, Maryland, to buses, automobiles, bicycles, and taxicabs.
(Photo: Paul A. Souders/CORBIS.)

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

COMING NEXT ISSUE

Newly installed variable message sign undergoes initial tests in Great Smoky Mountains National Park, Tennessee.

Transportation, National Parks, and Public Lands is the theme of feature articles scheduled for the July–August 2004 *TR News*. Topics include intelligent transportation systems and advanced technologies in national parks, bicycle and pedestrian facilities, transportation issues for urban parks, special fleet development, the National Park Transportation Scholar Program, and more.

Workers from the California Department of Transportation rebuild I-5 with long-life pavement.

Get In, Get Out, Stay Out!

Caltrans Proves Effectiveness of Pavement Renewal Approach

KIRSTEN R. STAHL AND MARIO A. GUTIERREZ

Stahl is District Materials Engineer, and Gutierrez is Senior Transportation Engineer, California Department of Transportation, Los Angeles. Stahl chairs the National Cooperative Highway Research Program Panel on Durability of Early-Opening-to-Traffic Portland Cement Concrete for Pavement Rehabilitation.

Six years ago, the California Department of Transportation (Caltrans), in coordination with the Federal Highway Administration and the Transportation Research Board (TRB), convened a weeklong Workshop on Pavement Renewal for Urban Freeways. Representatives from state transportation agencies, other public and local agencies, and nationwide contractors examined a major problem for highly urbanized areas—the timely repair of crowded freeways.

The week of discussions, brainstorming, presentations, and exchanges of ideas and information about innovative technologies focused on practical solutions. The workshop defined the concept that became the title of a TRB report released in 2000, *Get In, Get Out, Stay Out!*[1]

The publication presented the workshop's vision for roadway renewal: identify the most innovative and effective engineering practices and technologies that could provide a comfortable riding surface lasting for 40 years with minimal maintenance. These pavement characteristics would translate into decreased interruptions for road users and increased efficiency in moving goods and services.

Transportation agencies face a growing number of obstacles and time constraints in maintaining freeway facilities in safe and acceptable operating conditions. A dynamic and demanding society puts cars on the freeways at a rate that makes it almost impossible to keep up with repairs to the normal wear-and-tear.

Caltrans has dedicated resources to create and implement pavement renewal solutions in line with

[1] *Get In, Get Out, Stay Out! Proceedings of the Workshop on Pavement Renewal for Urban Freeways*. TRB, National Research Council, Washington, D.C., 2000. Available from TRB bookstore, www.TRB.org/bookstore/, or online at http://gulliver.trb.org/publications/sp/getin_getout_stayout.pdf.

the imperatives of get in, get out, stay out. Through experimental projects in Southern California, Caltrans has achieved results that are paving the way to long-lasting, minimal maintenance freeways.

Answering a Challenge

In a workshop challenge, teams of participants worked out solutions for reconstructing an approximately 16-mile segment of Interstate 710 (I-710). Also known as the Long Beach Freeway, I-710 is an arterial route serving one of the busiest ports in the world, as well as nine highly populated and industrialized communities. The roadway presented poor pavement conditions and high traffic volumes. Proposals for reconstruction had to meet the following specifications:

- Provide a pavement with a service life of at least 40 years,
- Minimize traffic disruptions,
- Ensure the safety of workers and highway users,
- Minimize short- and long-term user costs,
- Minimize roadway life-cycle costs, and
- Minimize the impacts on the community and the environment.

The teams visited the freeway segment, heard the views and expectations of representatives from the community and from public and private organizations, and developed proposals. The Caltrans engineering staff reviewed each team's solutions and calculated the costs.

Renewal Program Awaiting Launch

ANN M. BRACH

The Workshop on Pavement Renewal for Urban Freeways—or the Get In, Get Out, Stay Out workshop—influenced the development of the new Strategic Highway Research Program (SHRP II), proposed in the surface transportation reauthorizing legislation. SHRP II would receive $95 million over six years to advance research, technology, and methods for infrastructure renewal. The vision of the renewal program under SHRP II is that preservation, rehabilitation, and reconstruction activities on highway infrastructure will be carried out rapidly, with minimal disruption to users and communities, and will result in long-lived facilities.

The SHRP II renewal program covers a range of research topics, such as faster in-situ construction, offsite fabrication, inspection and monitoring with sensor technologies, contracting methods, disruption mitigation, customer relations, work zone traffic flow, design and construction of low-maintenance facilities, and preservation methods for high-traffic areas.

More details on the renewal program under SHRP II, as well as on the other component programs, are available on the TRB website at www4.TRB.org/trb/newshrp.nsf.

The author is Senior Program Officer, TRB Division of Studies and Information Services.

Sorting the Proposals

The proposals covered a range of scopes and budgets but shared the objectives of get in, get out, stay out. The common denominators were a low-maintenance and long-lasting pavement structure, abbreviated construction time, and minimal impact on the community. Each team developed plans for handling traffic and conducting community outreach, and each team described construction procedures and requirements for materials and equipment.

The proposals varied from full replacement of the portland cement concrete (PCC) pavement and of the bridges, at a cost of $191.5 million, to rehabilitation with recycling techniques and a polymer-based hot-mix asphalt overlay, at a cost of $64.9 million.

Each team analyzed ways to control the traffic for each solution, taking into account the traffic volumes, the impact on the surrounding communities, the contractor's access to the work site, the contractor's freedom to move construction equipment within the work area, and the configuration of the freeways and arterial highways within and beyond the project limits. Suggested methods varied from weeknight lane closures to full freeway closures on weekends, featuring counterflow operations and staged construction phases with movable barriers.

Another key point was the importance of a well-planned public awareness campaign. Implementing this insight, Caltrans formed a Task Group on Community Relations and Public Affairs several months after the workshop to develop guidelines for the public campaign for the reconstruction of I-710. The group drew up a list of the main considerations for an effective public awareness campaign:

- Message,
- Audience,
- Delivery of the message,
- Community feedback, and
- Measuring the results.

The group discussed each of these topics in detail and drew up specific recommendations for the Long Beach Freeway project.

Implementing Solutions

For more than a decade, get in, get out, stay out had been the goal in dealing with the heavy traffic volumes of Southern California's major cities. Workshop participants explored the premise that structural repairs to heavily traveled highways in densely populated urban areas can last more than 40 years with only minor interventions to restore ride quality.

Six years after the workshop, case histories of several Southern California projects—with asphalt concrete and PCC materials—demonstrate how Caltrans has put this philosophy into practice and gained valuable insights. But first, how did Caltrans approach the goals of get in, get out, stay out?

Get In

If morning traffic begins to peak at 5 a.m. and continues unabated in both directions until after 10 p.m., finding a productive time for construction is a challenge. The 7 intervening nighttime hours often are the longest available period for the construction of urban roadway projects. Making the most of that brief time requires specialized traffic handling, accelerated construction, early strength materials, and knowledge of best practices—which in many cases must be pioneered.

Extended construction periods, such as 55-hour weekend closures, frequently require upgrading of the shoulders, restriping, moving lanes for one direction into the opposite direction of travel (counterflow measures), placing quick-change concrete barriers, and establishing peak-directional flow corridors, which change the directions of lanes at different times of the day.

If the highway geometry permits, work can start on the shoulders and outside lanes to increase capacity, so that the change in flow will be minimal when the inside lanes are renewed or when long-term counterflow measures divert the traffic to parallel routes or into the opposite direction. First applied during the repairs after the Northridge earthquake in 1994, this approach allows the repair of long corridors without traffic interruption and with normal materials, which can keep costs down.

These measures require an extraordinary public awareness program to educate transportation supporters and users—such as politicians, management, motorists, professional drivers, and tourists—in making informed choices.

Get Out

The construction team must move quickly. Planning is necessary to make the work zone safe for workers and drivers, to close lanes quickly to traffic, to remove damaged pavement and replace it with high-performance materials that can gain strength in a few hours, and finally to return the work zone back to traffic in time for the morning commute.

Particularly useful are innovations such as quick-change concrete barriers, nonimpact pavement removal techniques, and very high early-strength cements that allow early opening to traffic. These involve specialty admixtures, precast segments, real-time testing equipment and methods that produce rapid results, and early-dry sawing techniques.

Traffic control incentives and disincentives—such as bonuses for early completion or charges to contractors for lane rentals during closures—have proved effective in keeping roadway openings on or ahead of schedule.

Stay Out

The get-in, get-out vision is for overnight highway repairs with few public inconveniences. The stay-out vision is for the repairs to last 20, 30, and 40 or more years, so that the driving public will encounter repairs on a roadway only once during a working career.

Some have questioned the effort and expense, if the improvements will not be long-lasting. Others expect a “quality dividend,” with the savings financing new roadways, safer buildings, and more schools and hos-

Birth of the Accelerated Construction Technology Transfer Team

FREDERICK D. HEJL

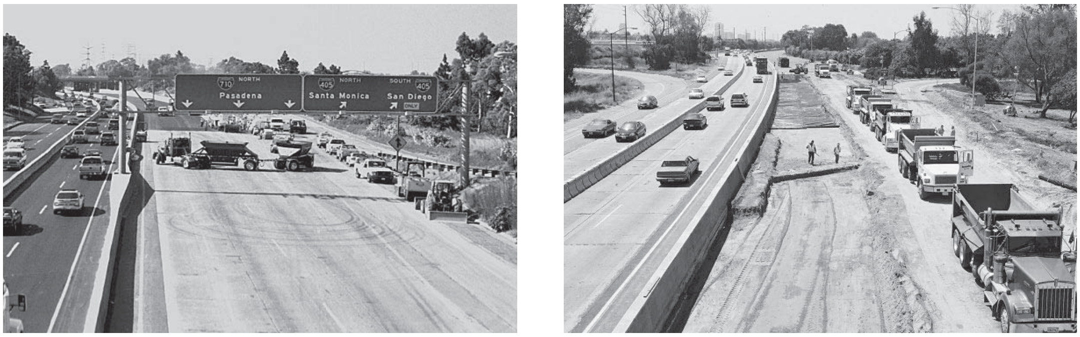
A November 2000 workshop convened construction executives and engineers from around the country to explore issues associated with accelerating the construction process. Conducted by TRB’s Accelerating Innovation in the Highway Industry Task Force and in cooperation with the National Cooperative Highway Research Program (NCHRP), the program raised such issues as innovative financing, innovative contracting, traveler mobility, constructability, long-life pavements and structures, prefabrication, geotechnical challenges, worker health and safety, utilities, and right-of-way. Many participants noted that solutions were complex and could not be developed issue by issue but required a multidisciplinary approach.

This observation generated the concept of the Accelerated Construction Technology Transfer (ACTT) team—national experts with a variety of technical skills who would meet with counterparts at a state agency considering an accelerated construction project. The ACTT members and the host agency staff would share experiences and discuss innovative ways to accelerate construction of the project, providing opportunities for interaction among representatives with different areas of expertise.

The Federal Highway Administration and the Technology Implementation Group (TIG) of the American Association of State Highway and Transportation Officials worked with the TRB task force and NCHRP to conduct two workshops to pilot-test the ACTT concept. The Indiana Department of Transportation hosted the first workshop in March 2002, and the Pennsylvania Department of Transportation hosted the second in April 2002. Both agencies had high-profile projects under way and found the sessions valuable.

Reports of the workshops are included in Circular E-C059, *Accelerated Highway Construction: Workshop Series Summary,* posted on TRB’s website (www.TRB.org/publications/circulars/ec059.pdf). FHWA and TIG are cosponsoring ACTT workshops for state agencies across the country (see box, page 6).

The author is Engineer of Materials and Construction, TRB.



Traffic is rerouted during the long-life asphalt concrete project on I-710.

pitals. With a quality, long-term focus, the repairs often can use familiar materials.

But with the financial burdens that all governments are facing, how can the vision be achieved? Specifications and testing must ensure that the materials are durable and ready to go into service at the appropriate time.

Interstate 710

The Long Beach Freeway has become the state's arena for implementing get in, get out, stay out projects. The 22-mile freeway is a major north-south Interstate for interregional and intraregional commuting and shipping.

I-710 passes through an urban corridor linking the

Accelerated Construction Technology Transfer Workshops

Completing Projects Faster, Safer, and Better

BILL BOLLES

Accelerated Construction Technology Transfer (ACTT) focuses on achieving the highway construction objectives of "get in, get out, stay out"—that is, get the job done and done right. Sponsored by the American Association of State Highway and Transportation Officials' Technology Implementation Group and the Federal Highway Administration (FHWA), ACTT incorporates innovative techniques, strategies, and technologies to minimize construction time and enhance quality and safety on large, complex, multiphase projects.

For a specific highway project or corridor, ACTT starts with a 2-day workshop, assembling a multidisciplinary team of 20 to 30 national transportation experts to work with host agency counterparts and other local transportation professionals (see box, page 5). The team evaluates all aspects of the project in search of techniques, methods, and measures that would help the agency achieve such goals as reducing construction time, improving work zone and traffic safety, and enhancing quality.

Skill Sets

A project may draw on the following skill sets:

- Right-of-way, utilities, and railroad coordination;
- Traffic engineering, safety, and intelligent transportation systems;
- Structures;
- Innovative financing and contracting;
- Worker health and safety;
- Geotechnical materials and accelerated testing;
- Long-life pavements and maintenance;
- Construction techniques, automation, and constructability;
- Environment and context-sensitive design;
- Roadway design and geometries; and
- Public relations.

Teaming Up

Seven ACTT workshops have been completed since September 2003. State departments of transportation (DOTs) have responded positively—five more workshops are scheduled for 2004, with many more in planning and discussion. Through FHWA Division Offices, the ACTT management team coordinates efforts with state DOTs to prioritize and schedule workshops.

In September 2003, Texas DOT hosted an ACTT workshop for Project Pegasus, the reconstruction of the I-35E and I-30 interchange and portions of the two major freeways, which serve downtown Dallas. Team recommendations included completing the Trinity Parkway, parallel to I-35, to function as a detour during construction; allowing the contractor to build a plant on-site, to minimize travel time and congestion; improving general materials specifications; setting up a dedicated incident management system; and establishing a variety of traffic-flow strategies. The goal is to complete the $760 million project in 4 years—3 years ahead of the original estimate.

In October, an ACTT miniworkshop focused on New Jersey's plans to improve a bridge on Route 46 in Bergen County. As a result of ACTT recommendations, work to replace the bridge deck and floor beams will take only 3 months and cost an estimated $3 million, instead of the originally anticipated 18 months at a cost of $10 million. The project is in design and will use precast elements, lightweight high-performance concrete, and fiber-reinforced polymer composites, allowing reuse of the previous substructure. Work is scheduled to begin in early 2005.

In December, Caltrans' ACTT workshop focused on the $75 central business districts of Long Beach and Pasadena with the central business district of Los Angeles. The facility also provides access to the Catalina Island ferries, the Port of Long Beach, the Port of Los Angeles, Long Beach Municipal Airport, Long Beach World Trade Center, truck terminals in the vicinity of Vernon, and California State University–Los Angeles near Route 10. Because of the major ports and terminals, I-710 serves a large volume of truck traffic, but the route also connects to recreational points.

Land Use

Land use varies along the I-710 corridor. Heavy industry predominates between Long Beach Harbor and the city of Commerce.

Plans for the Ports of Long Beach and Los Angeles envision an expansion of the facilities. Port access studies predict 223 million metric tons of cargo by 2010. Extensive redevelopment already has begun in the areas around the ports.

Nine-inch overlay of polymer-based asphalt laid on I-710 was specifically designed both to carry the projected traffic loads and to last 30 to 40 years with minimal maintenance.

North of the ports, land use changes to commercial and residential. Forecasts indicate a substantial increase in the commercial and residential infrastructure.

million French Valley Parkway project on I-15 between Temecula and Murrieta. The project includes a new interchange between the junctions with I-215 and SR-79. Among the recommendations were design modifications to eliminate two bridge structures and braided ramps; prefabrication of an entire bridge span; a dedicated incident management system; prequalification of material sources; and paving the median to serve as a detour during construction and to provide for future high-occupancy vehicle lanes.

Another December 2003 workshop, hosted by Louisiana DOT, focused on rehabilitating a 40-year-old elevated section of I-20 in Monroe. Recommendations included the completion of nearby projects beforehand to ease traffic flow; an aggressive incident management system with performance-based wrecker service; a smart work zone with cameras, variable message signs, and advance warning signs; and lane rental by the contractor for nightly closures of the mainline and certain ramps.

Montana DOT hosted an ACTT workshop in January 2004 to examine a $100 million project for upgrading a 50-mile portion of US-93 north of Missoula, within the Flathead Indian Reservation, home of the Confederated Salish and Kootenai Tribes. Recommendations aimed at reducing construction time from 5 to 3 years, with prefabricated structural components installed at night; preapproval of tribal sites to minimize inspection time; use of jet grouting; and establishment of a corridor management and communication team with representatives of the tribal governments.

Washington State DOT hosted a workshop in March for a project on SR-520 between I-5 and I-405 in Seattle that will include the replacement of a 40-year-old floating bridge across Lake Washington. The project will cost between $1.5 and $3.4 billion, depending on the number of lanes selected—the largest ACTT project so far. Recommendations included designing the simple pontoons first, so that construction can resume while the more complex pontoons are designed, as well as using self-consolidating concrete for pontoon construction. Washington State DOT expects to reduce construction time by 1 to 2 years.

In April, Tennessee DOT hosted an ACCT workshop to examine a $160 million project on a 2-mile stretch of I-40 between I-275 and Cherry Street in Knoxville. Recommendations to reduce construction time included adjusting the bridge span lengths to avoid the previous foundations and completing and opening a nearby roadway before the closure of I-40.

Oklahoma, Minnesota, Wyoming, Rhode Island, New Jersey, and Nevada have scheduled ACTT workshops. Other states, such as Wyoming, Utah, Hawaii, Wisconsin, Maryland, Idaho, Georgia, Massachusetts, Rhode Island, Oregon, Alabama, Arizona, and Virginia, have indicated interest in the program.

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Website

Federal Highway Administration: ACTT
www.fhwa.dot.gov/construction/accelerated/index.htm

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Facility Characteristics

The freeway facility ranges from 6 to 12 lanes. The southern 4 miles feature six 12-foot lanes with 8-foot shoulders inside and outside. The freeway widens to eight 12-foot lanes for the next 15 miles, with some sections of 12 lanes. The northern 3 miles revert to six 12-foot lanes with inside and outside shoulders 8 feet wide and a 46-foot median.

The route was built in 1954, with follow-up projects to accommodate increasing traffic demands. The pavement consists of three 9-inch layers—imported subbase material; granular base material, sometimes stabilized with portland cement; and PCC slabs on the riding surface.

Deterioration of the PCC pavement has been evident, particularly in the outer lanes (Lanes 3 and 4), because of truck traffic with heavy axle loads. Slab cracking, spalling (breaking, chipping, and fraying), depressions, and low-quality ride are common.

Recent improvements along the southern portion have improved traffic operations. The original metal-beam median barrier has been replaced with a PCC concrete barrier and PCC slabs have been replaced at spot locations in critical segments.

Operating Conditions

Average daily traffic (ADT) for I-710 in 2000 ranged from 140,000 to 218,000. The 20-year projections range from 153,000 to 227,000, with trucks comprising 8 to 15 percent of the totals. Peak direc-

Mix and Structure of I-710's Long-Lasting Pavement

CARL L. MONISMITH

California's I-710 project includes full-depth asphalt concrete sections, which replace portland cement concrete (PCC), and asphalt concrete overlays on cracked and seated PCC. The asphalt mix and pavement section structural designs rely on technologies developed in the Strategic Highway Research Program (SHRP) and employ innovative construction specifications, as well as requirements stemming from the work of the Caltrans Accelerated Pavement Testing (CAL/APT) Program.

The original pavement section consisted of PCC, cement-treated base, and aggregate base and subbase. The pavement, which opened to traffic in 1952, was in poor condition, since it had not received any overlays before the reconstruction. Rehabilitation included two strategies:

1. Crack and seat the PCC and apply an asphalt concrete overlay.
2. If an overlay would cause the clearance under a structure to fall short of the minimum, replace the PCC pavement with full-depth asphalt concrete sections, lowering the grade to provide the required clearance.

Evaluating Mixes

The Asphalt Pavement Association of California (APACA) supplied representative asphalt binders and aggregate that had been used for paving in the Los Angeles Basin. Included were two asphalt binders—an AR-8000 (PG64-16) conventional asphalt cement and a PBA-6a* (PG64-40) polymer-modified binder—and an all-crushed aggregate from the San Gabriel River Valley at Azusa.

Mix designs were based on the SHRP-developed repeated-load simple shear test. Results indicated that the mix with the PBA-6a* binder would sustain more equivalent single-axle loads (ESALs) than the mix with the AR-8000 binder. The PBA-6a* mix therefore was selected for the surface course.

To determine the necessary thickness of the full-depth section, both mixes were evaluated with the SHRP-developed fatigue test, which provided data for mechanistic-empirical analyses. The experience of CAL/APT, as well as of roadbuilders in Australia, indicated that the full-depth section should incorporate a "rich bottom." Two sets of fatigue tests were run on both mixes, one with the binder content that performed best on the simple shear tests and the second with a binder content 0.5 percent greater, corresponding to the defined rich-bottom condition.

Structural Sections

The resulting pavement section (Figure 1), designed for 200 million ESALs, consists of the PBA-6a* mix for the rut-resistant surface course and the AR-8000 mix with two different binder contents.

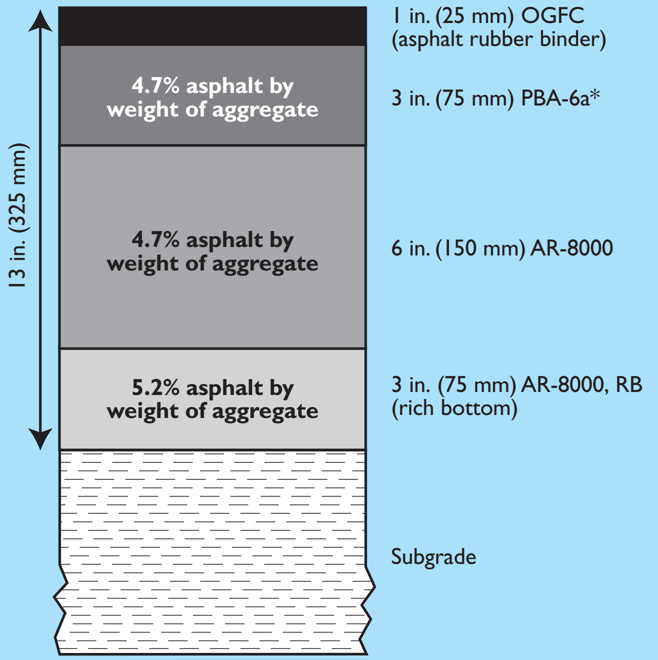


FIGURE 1 Structural section, full-depth asphalt concrete replacement of structure.

tional volumes range from 10,600 to 18,800 vehicles per hour. Accident data show 17 areas with high concentrations of accidents, mostly related to congestion.

Pavement Rehabilitation

The first experimental project, along 2.5 miles in the southern portion of the route, started construction in early 2001 and was completed in late 2003 at a cost of $21 million. The main challenge was handling the traffic in a 6-lane segment with an ADT of more than 145,000 vehicles, approximately 15 percent of which are trucks.

The project involved replacing the median barrier, widening the shoulder, and placing a 9-inch overlay of polymer-based asphalt (PBA). The PBA was specially designed both to carry the projected traffic loads and to last for 30 to 40 years with minimal maintenance. Traffic would have to be interrupted for the placement of more than 110,000 tons of asphalt concrete.

The project was divided into four phases:

1. Temporary barriers were placed on both sides of the median for protection, and the median area and concrete barrier were constructed.
2. The temporary barriers were moved to the outside edge of the traveled ways for widening the shoulders and for improving the drainage.
3. The PCC cracking and seating and the asphalt overlay were accomplished segment by segment, one side of the freeway at a time. During 55-hour

The AR-8000 mix with the larger binder content—the rich-bottom mix—was used for the lower layer because of the improved fatigue resistance. Most of the pavement sections use the AR-8000 mix because its stiffness is greater than that of the PBA-6a* mix, reducing the stresses in the subgrade.

An open-graded friction course with an asphalt-rubber binder serves as a noise-reducing layer. The course also reduces the potential for splashing and hydroplaning, as well as the surface aging of the PBA-6a* mix. The course will be replaced periodically.

Caltrans' experience influenced the design of the asphalt concrete overlay on the cracked and seated pavement. A section approximately 6 inches (150 millimeters) thick, with a saturated asphalt fabric as a stress-absorbing layer, had proved satisfactory for traffic in the range of 10 to 20 million ESALs.

The question was how much additional thickness would be required to sustain 200 million ESALs. No well-defined design procedures address reflection cracking, the primary mode of distress in cracked and seated pavement. Finite element simulations were performed for a series of sections containing both mixes. After analysis, the section shown in Figure 2 was selected; the materials and thicknesses were consistent with the full-depth section.

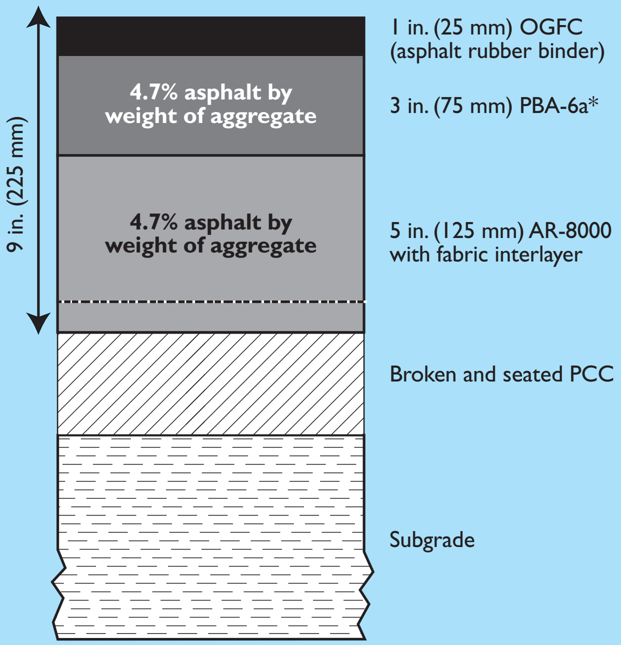


FIGURE 2 Proposed design for overlay on cracked and seated existing portland cement concrete structure.

Checks and Controls

To check the rutting resistance of the PBA-6a* and the AR-8000 mixes, APACA supplied aggregate and the two binders for construction of a test pavement at the Pavement Research Center, University of California, Berkeley. Heavy-vehicle simulator tests were conducted on an overlay that contained the two mixes placed on a jointed, plain PCC pavement. The study confirmed the mix designs that were based on results from the repeated-load simple shear test.

The successful performance of these pavements depends on careful control of the mix components, mix compaction, and layer thickness. In a departure from its standard practice, Caltrans recommended but did not specify mix designs. This allowed the contractor to select the materials to meet the mix performance requirements. The contractor, however, had to submit data from shear and fatigue tests for mix approval before construction, along with the materials for verification.

Caltrans, APACA, and the University of California–Berkeley partnered in determining the designs and the construction requirements. The partnership provided opportunities to implement new ideas and research results on a project for which traditional approaches were insufficient.

The author is R. Horonjeff Professor of Civil Engineering (Emeritus), University of California, Berkeley.

weekend closures, both directions of traffic were moved to the other side of the freeway, via predetermined openings in the median, with a movable barrier as a divider. Completing this phase required eight weekends.

4. A 1-inch wearing surface of asphalt concrete was placed during weeknight closures, and incidental and minor work was completed.

Keys to Success

The following measures contributed to the successful and safe completion of the project:

- Movable barriers with median openings for crossovers. The contractor was able to route both directions of traffic onto one roadway, allowing work on the other.
- Extended, 55-hour, weekend closures. The contractor was able to increase productivity with direct access to the work site and more space for equipment.
- Monetary incentives and disincentives in the contract. Special provisions encouraged the contractor to reduce the number of weekend closures for the asphalt concrete overlay—the contractor could earn a bonus of $100,000 for every reduced weekend closure or lose $100,000 for every added weekend closure. The original estimate was for 10 weekend closures to crack and seat the PCC pavement and place an 8-inch asphalt concrete overlay. Below overpasses, the contractor had to remove and replace the full structure of the pavement, lowering the roadway profile to meet vertical clearance requirements. The contractor completed the project successfully in 8 weekends, through extra effort and construction strategy.
- An effective and well-planned public awareness campaign. Starting before the project construction date, the public awareness campaign was a key in convincing industry, businesses, communities, and the general public to reduce trips during the weekend closures or to take clearly identified alternate routes.
- A carefully designed traffic management plan (TMP). Early in the design phase, a team of roadway engineers, traffic engineers, project managers, material suppliers, and representatives of the asphalt industry met regularly to determine and identify construction methods, traffic handling procedures, and production of materials. The TMP took into account traffic pattern characteristics, such as continuous 24-hour volumes, types of traffic, operating speeds, and calculations of delays. The design team relied on the TMP in handling traffic throughout the construction. Planners were able to determine the best closure times for the segment, the progressive closure of lanes on weekdays, law enforcement and emergency assistance needs, and detours and alternate routes to avoid traffic congestion.

The TMP made it possible to keep the traffic moving safely on one side of the freeway while the other side was under construction. The project won the 2003 Roadway Work Zone Safety Awareness Award sponsored by the American Road and Transportation Builders Association and the National Safety Council for innovations in technology and methodology.

Upcoming Projects

With the success of the experimental project, Caltrans is applying the long-life pavement renewal strategy to a 17-mile section of the northern portion of the route, in two separate projects.

I-405 to Firestone Boulevard

The 9-mile project from I-405 to Firestone Boulevard traverses six communities. The pavement characteristics are similar to those in the southern portion of I-710, except for the interchange with another major freeway that incorporates current geometric and pavement standards. The project is in design, with an estimated cost of $110 million.

Traffic will be handled with crossovers in combination with a movable barrier system, placing traffic in both directions on one side of the roadway. The size and complexity of the project requires the deployment of intelligent transportation systems to ensure safe operating flows. The contractor will place more than 340,000 tons of asphalt concrete during 30 to 40 weekend closures. Construction is expected to begin in late 2005.

Firestone Boulevard to I-10

The second project will close the 8.1-mile gap between Firestone Boulevard and I-10. The project's design features again are similar to those of the first but include the widening of 15 bridges—a combined length of 16 lane-miles. The project cost estimate is $220 million and construction is planned for late 2007.

PCC Experiments

Nonimpact Pavement Removal

Applying a new technique for removing concrete panels, suggested by the Special Pavement Studies of the Strategic Highway Research Program, Caltrans found that the treated bases of the roadways often were in excellent condition. The assumption had been that if the pavement was broken, so was the base.

Prefabricated portland cement concrete panels installed on I-10.

Quick-change movable barrier transfer–transport machine minimizes setup and removal of traffic closures.

On I-5 in Northern California, Caltrans inserted eye-bolts into each broken panel piece for lifting out with a backhoe. On I-10 in Santa Monica, crews sawed larger panel segments into bucket-sized pieces, which were then lifted out with a backhoe. In both cases, the treated base of the roadway was in excellent condition.

A demonstration in Pomona removed 100 lane-feet in 20 minutes, a production rate of 300 lane-feet per hour. Replacing 300 lane-feet of 8-inch concrete pavement at normal concrete production rates of 90 cubic yards per hour would take 3 hours.

Allowing a base in good condition to remain in place can reduce material costs and construction time by more than 30 percent. The method received an Excellence in Transportation Award in 1995 and is specified on all pavement rehabilitation projects in California.

Fast-Setting Concrete

When panel replacements with a compressive strength of 80 pounds per square inch (psi) failed under traffic at 400 psi, Caltrans set a priority of achieving 400-psi pavement. The first attempt, known as fast-setting hydraulic cement concrete (FSHCC), used cements that gained strength rapidly when mixed with water. The mineral content differed from that of portland cement. FSHCC was used initially to speed up soil-cement backfills on I-10 in Los Angeles during repairs after the Northridge earthquake.

FSHCC had to meet durability requirements, such as sulfate resistance, low shrinkage, and high thermal stability. Also specified was a strength gain—that is, thorough hardening—3, 4, or 8 hours before opening to traffic. Although portland cements with accelerating admixtures could meet those specifications, contractors frequently chose specialty cements instead.

A contractor on I-110 in Los Angeles first proposed paving with FSHCC to reduce cost; FSHCC already had been used for panel replacement projects. Many mixes added retarders to allow delivery from the plant and placement at the site before strength gain. To avoid delays caused by retarders, some projects mixed the nonreactive materials, such as aggregate, water, and fly ash, at the plant and added the cement from a silo or superbag at the site.

An FSHCC project on I-5 in Burbank achieved an opening strength of 400 psi in less than 2 hours. A demonstration placed 500 cubic yards of ready-mixed FSHCC with a single-lane slip-form paver at night on I-605 in Santa Fe Springs. Another project on I-60 in

Construction crews work at night to minimize delays for motorists.

Traffic on I-10 shifted from four to two lanes during a 55-hour weekend closure.

Pomona placed 4,000 cubic yards from an on-site batch plant, with end-dump trucks in front of a two-lane-wide slip-form paver, at summer temperatures of 100 degrees and higher.

The demonstrations culminated in the rehabilitation of 14 lane-miles of pavement on I-10 in Pomona. The project drilled tie-bars and placed dowel bars during an extended weekend closure and 7-hour nightly closures, protected by quick-change concrete barriers. The project received the 2001 American Concrete Pavement Association Excellence in Concrete Pavement Award for Restoration and for Transportation Management, the California 2001 Tranny Award for Transportation Management, the Caltrans 2001 Partnering Award (Bronze), the 2001 Marlin J. Knutson Award for Technical Achievement, and California's 2002 Excellence in Transportation Award for Innovation.

Rapid Strength Concrete

Caltrans revised the FSHCC specifications to allow more design options and renamed the material rapid strength concrete (RSC). The RSC specification still requires a compressive strength of 400 psi when opening to traffic.

A major revision is to determine the time for opening from data in the traffic control charts. The contractor must select and test a mix that will meet the strength and traffic control requirements. A 7-hour closure requires a fast mix, with strength gain in less than 4 hours. On longer closures—such as an extended weekend of 55 hours—the contractor could select a 12-hour mix and change to a faster mix near the end of the closure period.

In response to the specifications for early opening to traffic, several companies have developed new accelerating and retarding admixtures, improving an already successful endeavor.

CA4PRS Software Generates Pavement Rehabilitation Strategies

EUL-BUM LEE, JOHN T. HARVEY, AND MICHAEL M. SAMADIAN

A new decision-making tool is helping design, construction, and traffic engineers select construction schedules that minimize traffic delay and agency costs on highway rehabilitation and reconstruction projects. CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies) is a software package for estimating how much pavement can be rehabilitated or reconstructed under different traffic closure strategies with a project's constraints of pavement design, lane closure tactics, schedule interfaces, and contractor logistics and resources.

"What If" Scenarios

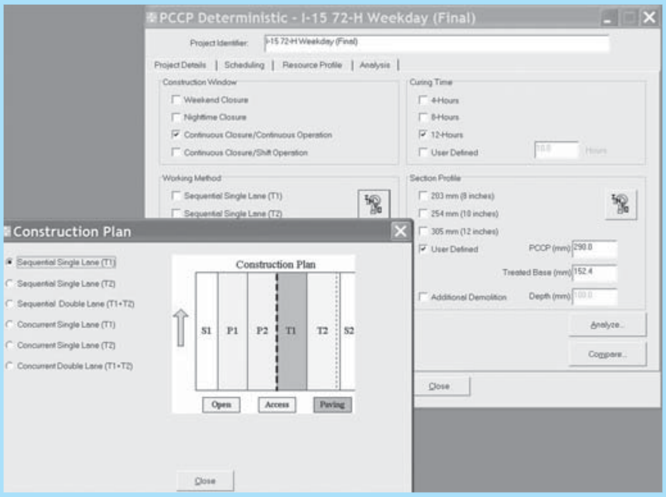
CA4PRS evaluates "what if" scenarios for highway rehabilitation by comparing projections for the following variables:

- Rehabilitation strategy: portland cement concrete (PCC) reconstruction, crack and seat PCC and with asphalt concrete overlay, or full-depth asphalt concrete replacement.
- Construction window: nighttime closures, weekend closures, continuous closures, or combinations.
- Lane closure tactics: number of lanes to be closed for rehabilitation—partial or full closures of the roadway.
- Material constraints: mix design and curing time for concrete and cooling time for asphalt.
- Pavement cross-section: thickness of new concrete or asphalt concrete.
- Concrete pavement base types: lean concrete base or asphalt concrete base.
- Contractor's logistical resource constraints: location, capacity, and number of rehabilitation equipment available—for example, batch plants, delivery and hauling trucks, and paving machines.
- Scheduling: mobilizing and demobilizing workers and equipment, installing traffic controls, and establishing the time needed before, between, and after the various activities.

The software is designed to help transportation agencies and paving contractors make sound construction project management decisions at the planning, design, and construction stages of a highway rehabilitation project. The calculations also are useful for comparing the cost savings from rehabilitation alternatives during the estimating and project control stages.

Software Connections

CA4PRS employs Miscrosoft (MS) Visual Basic 6.0 in an MS Windows environment, with an MS Access 2000 database. A knowledge-based



CA4PRS input screen for concrete rehabilitation analysis.

Precast Concrete Panels

These advances have improved the state of the practice of urban pavement renewal, but several issues still remain: providing the structural capacity to meet increasing traffic volumes, ensuring the quality of the work performed at night, and achieving all-weather construction.

A demonstration project is under way on I-10 in El Monte, to install PCC pavement panels that are prestressed, precast, and posttensioned—that is, reinforced with high-strength steel cables. The method incorporates prestressed steel and posttensioning to allow durable, in-kind replacements. Because the fabrication occurs before assembly on the job site, nighttime temperatures, quality, and the time to strength gain cease to be issues.

Even without posttensioning, the method allows replacement of individual panels. Stockpiled panels can be cut to size and placed on a bed of grout for emergency and routine replacements.

Workshop Legacy

The Workshop on Pavement Renewal for Urban Freeways shared and stimulated new ideas, viewpoints, and expectations from diverse sectors of freeway users. The exercise assembled multidisciplinary transportation teams to find solutions to a common concern.

The innovative and creative concepts articulated during the workshop have produced a successful result for Caltrans in the experimental project on the south portion of I-710. This achievement may spark application of the principles to renewing other freeways not only in California but in other states.

Website

Caltrans District 7 (Los Angeles and Ventura Counties): I-710 Projects
www.dot.ca.gov/dist07/710_rehab/index.shtml

computer model, CA4PRS allows deterministic or probabilistic modes of operation; the probabilistic mode uses Monte Carlo simulations.

CA4PRS can be incorporated into traffic simulation models and *Highway Capacity Manual* calculations, to maximize on-schedule production and to minimize costs to the agency and road users in delays during long-life pavement rehabilitation and reconstruction. This is essential for achieving the goals of accelerated construction, fewer traffic delays, and longer-life pavement. Calculations of traffic capacity with CA4PRS also facilitates problem-solving teamwork by traffic, construction, design, and maintenance engineers.

The CA4PRS model was developed with funding from the Caltrans Division of Research and Innovation. The University of California Pavement Research Center in Berkeley programmed the software with pooled funding from the Federal Highway Administration and the State Pavement Technology Consortium of California, Minnesota, Texas, and Washington.

Planners relied on CA4PRS evaluations for I-710 Long Beach rehabilitation project.

Field Deployment

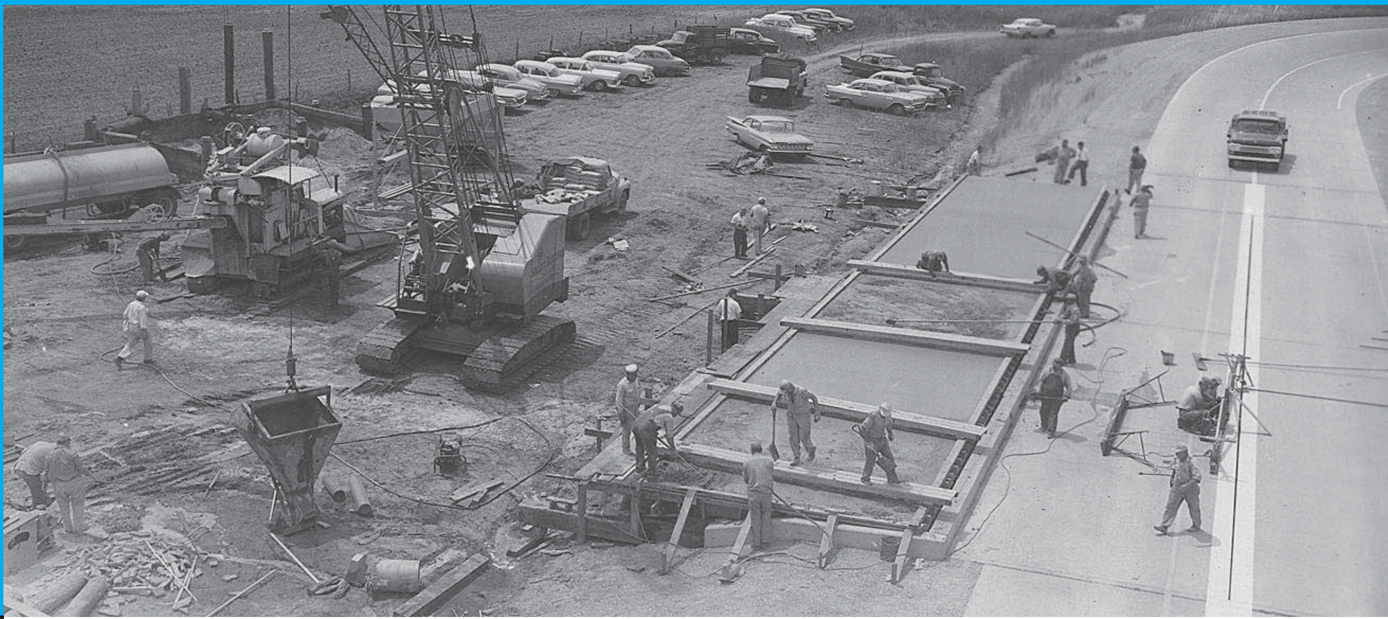
The I-10 project in Pomona, which placed long-life, fast-setting hydraulic cement concrete during a 55-hour weekend closure, produced data that verified the software calculations. CA4PRS also was used to evaluate construction plans for the I-710 project in Long Beach, which placed long-life asphalt pavement during eight weekend closures.

CA4PRS provided early input for the ongoing I-15 Devore reconstruction project in San Bernardino, as part of the analysis to select the most economical rehabilitation strategy. After the overall comparison and justification with CA4PRS, Caltrans decided on continuous weekday closures to accelerate construction of the I-15 project, with around-the-clock operations for 72 to 96 hours, depending on the length of the segment. The strategy will save millions of dollars for Caltrans and for road users, compared with the traditional approach of short, nighttime closures.

The Caltrans Division of Research and Innovation and its Partnered Pavement Research Program are completing a CA4PRS outreach and deployment program for pavement and traffic engineers, particularly in metropolitan districts. The outreach includes 1-day workshops in California and the three other consortium states.

For more information, see the Caltrans CA4PRS website, www.dot.ca.gov/research/raodway/ca4prs/ca4prs.htm.

The authors are with the Caltrans Partnered Pavement Research Program. Lee is Research Engineer, University of California, Berkeley; Harvey is Associate Professor, University of California, Davis; and Samadian is Division Chief, Caltrans Division of Research and Innovation, Sacramento.



THE AASHO ROAD TEST
LIVING LEGACY FOR HIGHWAY PAVEMENTS

KURT D. SMITH, KATHRYN A. ZIMMERMAN, AND FRED N. FINN

Smith is Program Director, Applied Pavement Technology, Inc., Champaign, Illinois, and a member of the TRB Rigid Pavement Design Committee. Zimmerman is President, Applied Pavement Technology, Inc., and a member of the TRB Maintenance and Operations Management Committee, the Asset Management Committee, and the Pavement Monitoring, Evaluation, and Data Storage Committee. Finn, who participated in the AASHO Road Test as liaison for the Asphalt Institute, is a consultant in Monticello, Illinois, a member of the National Academy of Engineering, and an emeritus member of the TRB Flexible Pavement Design Committee.

The American Association of State Highway Officials[1] (AASHO) Road Test, a major research initiative conducted from 1958 to 1960 near Ottawa, Illinois, continues to influence the pavement and transportation community. The project not only evaluated the performance and behavior of pavement structures under a variety of axle loadings but also investigated the performance of highway bridge structures under known loading conditions, as well as the effects of vehicle cost allocation, military road transport, and more (*1–7*).

The pavement construction, pavement monitoring, and data analysis activities conducted at the Road Test established many standards and protocols and helped define many pavement design, construction, and evaluation practices. Four decades after the completion of the Road Test, the AASHO design procedures remain the cornerstone for both rigid and flexible pavement design in the United States, as well as in other countries. In addition, researchers often use data from the Road Test in a variety of ways unforeseen by the original developers.

The approaching 50-year anniversary of the AASHO Road Test construction prompts a look back at the development, features, and characteristics of this major pavement research initiative.

Building the Concept

Individual states or highway agencies conducted most of the early road tests, pursuing design topics unique to local conditions. Funding constraints often limited the size and scope of these tests.

[1] Now the American Association of State Highway and Transportation Officials.

The AASHO Executive Committee first authorized a research project sponsored by two or more states in 1948. Road Test One-MD was conducted from 1950 to 1951 in La Plata, Maryland, south of Washington, D.C. (*1*). Even as this road test was under way, however, the transportation community recognized the need to broaden the scope of pavement research.

The AASHO Committee on Highway Transport envisioned a series of regional road tests conducted by regional associations. The first, the Western Association of State Highway Officials (WASHO) Road Test, conducted from 1952 to 1954, focused on flexible pavement performance. A second regional road test was planned for rigid pavements.

State highway agencies, however, were most concerned about accelerated pavement deterioration and increased maintenance costs from the "increases in the magnitude and frequency of axle loads" (*1*). Although the general understanding was that increased axle loads contributed to pavement deterioration, little information was available to draw conclusions about the effects of axle loads on pavement behavior.

Recognizing this need, the AASHO Committee on Highway Transport authorized the Road Test Advisory Committee (RTAC) of the Mississippi Valley Conference of State Highway Departments in 1951 to develop a comprehensive plan for a road test. The test would address the effect of axle loads on pavement behavior, the economic issues associated with vehicle operating costs and agency roadway costs, and the relationships between vehicle weight and road design (*1*).

RTAC envisioned a road test with both rigid and flexible pavements and a range of cross sections constructed for testing under axle loads above and below the statutory limits. This vision evolved into the AASHO Road Test. Table 1 summarizes some of the milestones in the planning, construction, and conduct of the AASHO Road Test.

Working on the 1 million applications in each Road Test lane.

TABLE 1 AASHO Road Test Timeline

Year	Event
1950	◆ AASHO regional associations agree to series of regional road tests.
1951	◆ Regional road test planned for Midwest. ◆ Road test scope expanded to include rigid and flexible pavements and wider range of cross sections and axle loads. ◆ Expanded scope approved, and bridge spans included. ◆ Working Committee appointed.
1952	◆ Site at Ottawa, Illinois, selected and approved by AASHO Committee on Highway Transport.
1953	◆ Plan developed and approved for states to share cost of road test. ◆ Cost estimate developed for 2-year test with 4 test loops and 24 vehicles plus 8 standby units.
1954	◆ States receive request for financial support. ◆ Number of vehicles in each test lane increased from 3 to 6. ◆ AASHO formally approves AASHO Road Test in Ottawa, with concurrence of Illinois Division of Highways.
1955	◆ AASHO asks HRB to administer and direct AASHO Road Test, and HRB accepts. ◆ Working Committee final report provides guidance on administration of Road Test. ◆ HRB opens field office and hires staff.
1956	◆ Walter McKendrick hired as Project Director. ◆ Two additional loops added to test light axle loads and to perform special studies. ◆ Construction of facility begins in August.
1958	◆ Test traffic begins October 15.
1960	◆ Regular truck traffic ends November 30.
1961	◆ Interim design procedures published. ◆ AASHO Road Test results used to set load limits, improve design procedures, and validate pavement design models.

Project Scope

The scope of the AASHO Road Test was modified several times from 1951 until construction began in August 1956. Development of the road test plans was the task of a Working Committee established at the request of RTAC.

Under the direction of Edwin Finney, Michigan State Highway Department, and with assistance from such notable engineers as Francis Hveem, California; Emmitt Chastain, Illinois; Charles Allen, Ohio; Tilton Shelburne, Virginia; William N. Carey, Jr., Highway Research Board[2] (HRB); and Roy Jorgenson, National Highway Users Foundation, the Working Committee functioned as a subcommittee of the AASHO Committee on Highway Transport.

The committee charge was to encourage state participation in the road test; recommend a site for the project that met established requirements; estimate the project cost; and establish financial responsibility for construction and administration (*1*). At the request of the AASHO Committee on Bridges and Structures, the project was expanded to include bridge spans.

[2] Predecessor to the Transportation Research Board.

Test Location

In July 1952, the Working Committee proposed a site for the Road Test between Ottawa and LaSalle, Illinois (Figure 1). The site met the predetermined requirements for temperature, frost penetration, and soil conditions and was located on a right-of-way that would become part of a planned freeway, Interstate 80 (*1*). Moreover, the proposal had the endorsement of the host state.

The environmental and subgrade conditions at the site were representative of a good portion of the United States. The Committee on Highway Transport immediately approved the site, and preliminary site investigations and the construction of support facilities soon began.

Test Objectives

Although the general scope of the project had evolved throughout the early planning, project objectives had not yet been specified. In 1957, the National Advisory Committee, under the direction of Kenneth B. Woods, Purdue University, released the following specific objectives for the Road Test (*1*):

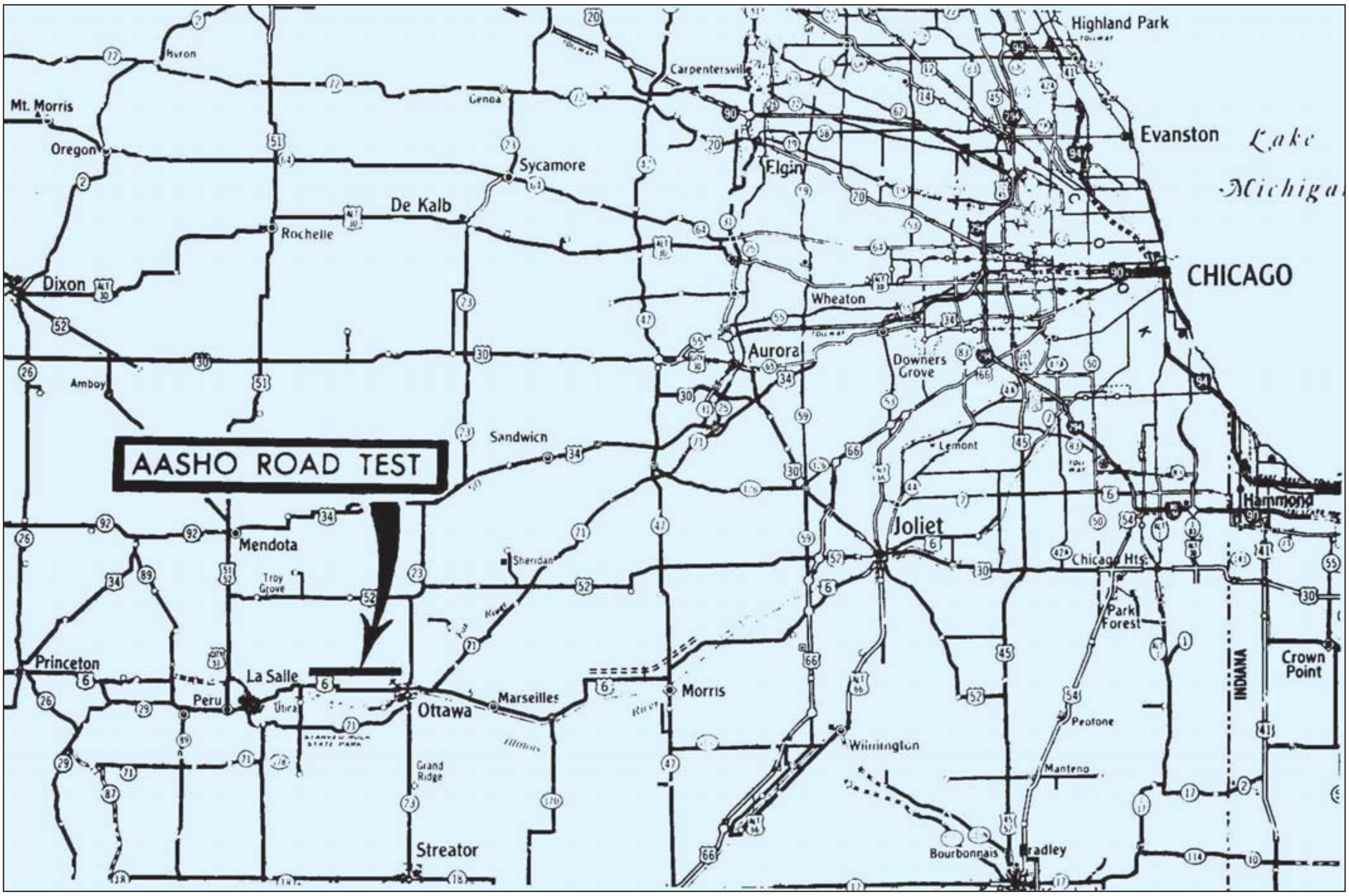


FIGURE 1 General site location for AASHO Road Test (*1*).

TABLE 2 In-Kind Contributions to Construction and Operation of AASHO Road Test (*1*)

Contributions	Contributing Organizations
Technical advice and resident task force	Illinois Division of Highways
Personnel for construction	Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, Oklahoma, and Wisconsin State Highway Departments
Assistance to performance rating panel	Minnesota and Indiana Highway Departments
Technical advice and services	Purdue University, University of Illinois, Lehigh University, American Petroleum Industries, Automobile Manufacturers Association, and Truck Trailer Manufacturers Association, including member companies
Participation in materials testing	Portland Cement Association, Asphalt Institute, and several states
Resident observer-consultants	Asphalt Institute, Portland Cement Association, American Trucking Associations, Canadian Good Roads Association, Ontario Department of Highways, and German Highway Research Board
Equipment personnel and technical advice in performing skid resistance experiments	General Motors Corporation
Equipment, personnel, and technical advice in dynamic testing of flexible pavements	Shell Oil Company

1. To determine the significant relationships between the number of repetitions of specified axle loads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphalt concrete, plain portland cement concrete, and reinforced portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.

2. To determine the significant effects of specified vehicle axle loads and gross vehicle loads when applied at known frequency on bridges of known design and characteristics. The bridges will include steel I-beam design, conventional reinforced concrete design, and prestressed concrete design.

3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tire size and pressures, and heavy military vehicles, and to correlate the findings of these special studies with the results of the basic research.

4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions in a satisfactory condition until discontinued for test purposes.

5. To develop instrumentation, test procedures, data charts, graphs, and formulas, which will reflect the capabilities of the various test sections and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways, and in determining the most promising areas for further highway research.

The first, third, fourth, and fifth objectives related to pavement research; the second objective related to bridge research.

Project Financing

The cost of the Road Test was estimated at more than $27 million—approximately $185 million in today's dollars. Financing was shared by the states, the Bureau of Public Roads[3] (BPR), industry, and the Department of the Defense through allocated funds, contributed services, and other forms of assistance.

BPR and the state of Illinois covered most of the construction costs through federal-aid funding. The Department of Defense provided the test vehicle drivers, and several other agencies contributed staff and services. Table 2 lists agencies that contributed in-kind services and financial support.

Project Administration

The administration and direction of the AASHO Road Test was the responsibility of HRB, a section of the National Academy of Sciences-National Research Council's (NAS-NRC) Division of Engineering and Industrial Research (*1*). Several advisory committees and panels were established to

[3] Forerunner of the Federal Highway Administration.

Researchers record bridge data on film.

Engineer Behind the Wheel

McKendrick, circa 1960

AASHO Road Test Project Director Walter Bamford McKendrick, Jr., was a graduate of the University of Delaware and Yale University. He worked for the Delaware State Highway Department in Dover from 1936 to 1956 in many capacities, including rodman, inspector, traffic engineer, planning engineer, and finally chief engineer.

In 1956, he accepted the position of Project Director for the AASHO Road Test with the Highway Research Board, serving until 1962. Always aware of the target of 1 million traffic applications during the 2-year test, McKendrick often instructed the pavement monitoring and maintenance crews during loop closures, "Take all the time you want, as long as you are off the road when the trucks are back in service."

After the Road Test assignment, McKendrick worked for the Portland Cement Association in Skokie, Illinois, until 1974. He then served at the Federal Highway Administration as Chief of the Foreign Projects Division until 1979. McKendrick died in February 2004.

support HRB's efforts, including panels on technical issues such as statistics, data analyses, and soils.

Walter B. McKendrick, Jr., appointed Project Director in April 1956, guided the day-to-day operation of the AASHO Road Test (see box, above). Carey served as Chief Engineer for Research. Working under their supervision were staff who addressed technical issues. NAS-NRC hired Peter Talovich to manage business and financial matters in an office at the site.

Many other engineers participated in the research as loan staff, and more than 400 military personnel were assigned to the project's traffic operations. Other staff were hired locally. Table 3 (below) lists some of the key project personnel.

Road Test Construction

Test Loops and Layout

The original program plan, submitted in 1953, called for the construction of four major test loops with eight traffic lanes; three test vehicles would operate in each lane during a 2-year period. Several modifications were made to the scope of the project during the next few years, and by May 1955 the Road Test had expanded to a six-loop facility that would employ a truck fleet of 126 (*8*).

The main structure consisted of the four large loops—Loops 3 through 6—which had more substantial pavement designs subjected to heavier truck loadings. Of the two smaller loops, Loop 1 was constructed to evaluate the effects of environment on pavement performance and thus was not exposed to regular truck traffic but was subjected to static load testing. Loop 2 represented lower-volume roadway designs for truck loadings. Figure 2 shows the layout of the test loops.

Each traffic loop consisted of two straight tan-

TABLE 3 Key Personnel for AASHO Road Test (*1*)

HRB Technical Staff	**Howard H. Boswell**, Maintenance Engineer
Walter. B. McKendrick, Jr., Project Director	**Rex C. Leathers**, Engineer of Special Assignments
William N. Carey, Jr., Chief Engineer for Research	**Henry C. Huckins**, Supervisor, Instrument Laboratory
Peter Talovich, Business Administrator	**W. J. Schmidt**, Chief, Public Information
Arthur C. Tosetti, Assistant to Project Director	**Donald R. Schwartz**, Engineer of Reports
W. R. Milligan, Assistant Operations Manager	**H. R. Hubbell**, Assistant Engineer of Reports
D. L. Thorp, Shop Superintendent [H. H. Cole (1958)]	
Alvin C. Benkelman, Flexible Pavement Research Engineer	**Staff Consultants and Observers**
L. E. Dixon, Assistant Flexible Pavement Research Engineer	**B. E. Colley**, Portland Cement Association
H. M. Schmitt, Assistant Flexible Pavement Research Engineer	**Fred N. Finn**, Asphalt Institute
Frank H. Scrivner, Rigid Pavement Research Engineer	**S. M. King**, American Trucking Associations [R. A. Lill (1955–1957)]
W. Ronald Hudson, Assistant Rigid Pavement Research Engineer	**R. I. Kingham**, Canadian Good Roads Association [G. D. Campbell, (1956–1957)]
Ivan M. Viest, Bridge Research Engineer	**W. E. Teske**, Portland Cement Association
J. W. Fischer, Assistant Bridge Research Engineer	**G. A. Wrong**, Province of Ontario, Canada
Paul E. Irick, Chief, Data Processing and Analysis	**E. R. Feldman**, Association of American Railroads
R. C. Hain, Assistant Chief, Data Processing and Analysis	**E. J. Ruble**, Association of American Railroads
James F. Shook, Materials Engineer [L. Q. Mettes (1956); Moreland Herrin (1958)]	**Rockwell Smith**, Association of American Railroads

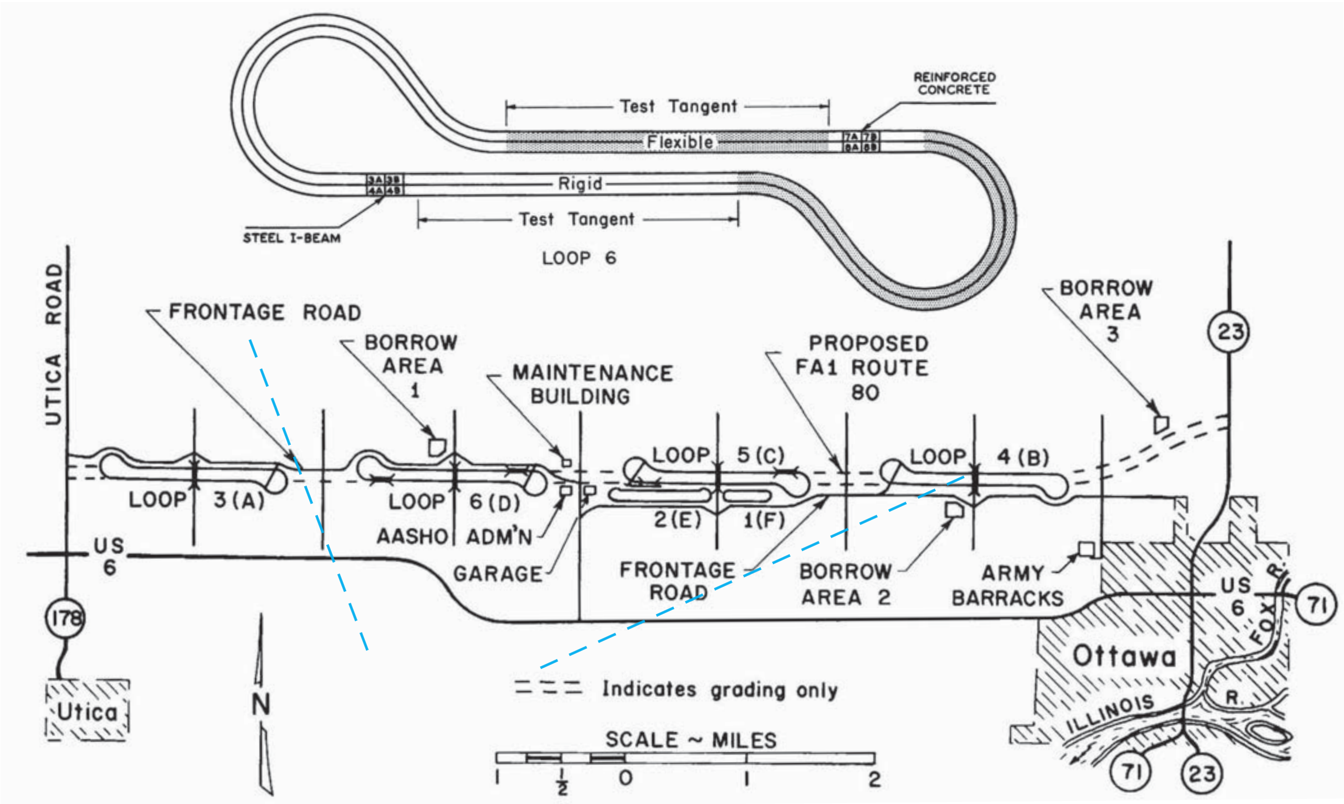


FIGURE 2 Layout of test loops at AASHO Road Test (2).

gent sections connected by a superelevated—that is, banked—turnaround at each end. Tangent lengths were 6,800 feet for Loops 3 through 6, 4,400 feet for Loop 2, and 2,000 feet for Loop 1. The turnarounds for the four main loops had 200-foot radii and were superelevated so that traffic could operate at 25 miles per hour (mph).

The large loops had two traffic lanes, each subjected to trucks with specific axle types and axle loads. The two traffic lanes also made it easy to incorporate the tangent sections directly into Interstate 80 at the conclusion of the Road Test.

The northern tangent and the eastern turnaround of each loop consisted of asphalt concrete (AC) test sections; the southern tangent and the western turnaround of each loop consisted of portland cement concrete (PCC) test sections (see Figure 2). Each tangent consisted of a series of short test sections separated by a transition pavement segment that was not studied. Each test section was separated into two identical pavement sections by the centerline of the pavement, as specific truck axle types and axle load combinations operated in each lane. A total of 836 test sections were constructed in all loops—468 for flexible pavement and 368 for rigid pavement.

Designing for Variables

Planning discussions considered the design variables and the associated levels for each pavement type. The Statistical Advisory Panel recommended a full factorial design for the pavements within each tangent—that is, at least one structural section would be included for each combination of variables and variable levels (*1*). This made it possible to determine the separate and interacting effects of specific pavement design variables on performance—something that earlier tests, like the WASHO Road Test, had not always been able to do.

Traffic on Loop 2.

Road Test Jeopardy

- Trucks on the main traffic loops averaged 35 miles per hour.
- During testing, 141 crashes occurred, with two fatalities.
- Broadcast band radios were installed in all vehicles in 1959 to relieve the monotony of driving the test loops.
- Approximately 1.25 million cubic yards of earth were moved in preparation for the Road Test—enough dirt to cover a football field more than 26 feet high. Approximately one-half of the dirt was used in the upper 3 feet of the embankments for the test loops.
- Because the pavement depths varied, the relative vertical position of the embankment material had to vary for each individual test section, to maintain longitudinal grades.

Truck crash on Loop 8.

The principal factorial variables for the flexible pavement test sections were AC surfacing thickness, base thickness, and subbase thickness. For the rigid pavement test sections, the principal factorial variables were PCC slab thickness, subbase thickness, and pavement type—jointed reinforced or jointed nonreinforced. All of the rigid pavement test sections contained dowels in the transverse joints. The reinforced sections had contraction joint spacings at 40 feet, and the nonreinforced sections had contraction joint spacings at 15 feet.

In addition, sections were constructed in each loop for studies of selected pavement variables, but because of space limitations, these were not full factorial designs. The flexible pavement experiment included studies on subsurface pavement layers, surface treatments, paved shoulders, and base types; the rigid pavement experiment featured additional studies on subsurface pavement layers and on shoulder paving with no subbase.

Construction

HRB opened its field office in Ottawa, Illinois, in July 1955 and was joined in August by a task force from the Illinois Division of Highways (*1*). The HRB group began assembling staff for the construction and analysis, and the Illinois group began preparing plans, letting and awarding construction contracts, and providing the engineering supervision of the test facility.

Construction proceeded in three overlapping phases (*1*):

- Earthwork: August 1956 to fall 1957;
- Bridge construction: October 1956 to April 1958; and
- Paving: late summer 1957 to July 1958.

Planners had recognized that many sources of variability would emerge from the performance data and made strong efforts to control all construction and materials variables to ensure uniformity. In an appendix to the Road Test layout, the Working Committee proposed construction and material requirements for the pavements (*9*). The requirements were based on a 1953 review of state highway practices, so that general construction procedures and controls would conform with nationwide practice, modified as necessary to obtain the required uniformity (*2*).

The final set of specifications was developed later (*10*), and construction adhered strictly to the specifications. The intent was for the materials, mix designs, and density requirements to be representative of those used in normal highway construction, and for the embankment and component layers of the pavement structure to be exceptionally uniform throughout all test sections, so that the behavior of the test sections could be related directly to their structural depth and layer composition (*1*).

Special detachment of soldiers drove and maintained the Road Test vehicle fleet.

Traffic and Maintenance

Truck Operations

Test traffic was inaugurated on October 15, 1958. As part of the experimental design, commercial trucks and tractor-semitrailer combinations of specified axle types and loadings were assigned to a lane of each test loop. Tractor-semitrailers were assigned to the four large loops (Loops 3-6); Loop 2 carried only light trucks with 2,000- and 6,000-pound single-axle loads (Figure 3); no regular truck traffic was assigned to Loop 1.

Under a cooperative agreement with the Department of Defense, a special military unit, the Army Transportation Corps Road Test Support Activity, supplied, supported, and supervised the traffic operations. The unit initially consisted of 300 soldiers, peaked at more than 450, and quartered in facilities near the eastern end of Loop 4.

The original truck fleet for the Road Test consisted of 70 vehicles: 14 small, single-unit trucks and 56 tractor-trailers. This traffic at first operated 18 hours and 40 minutes a day on a 6-day schedule, leaving a little more than 5 hours for pavement and vehicle maintenance, special studies, and routine measurements. The traffic schedules called for the operation of six vehicles per lane in Loops 3 through 6, four vehicles per lane in Lane 1 of Loop 2, and eight vehicles in Lane 2 of Loop 2. One standby unit was available for each lane.

In 1959, researchers took measures to increase the loading rate, after recognizing that the traffic rate would not produce the desired 1 million axle loads during the 2-year test. First, additional trucks were purchased to bring the total fleet to 126 vehicles (*3*). The density of vehicles also was increased on each loop, so that by January 1960, 10 vehicles were operating in each lane of the four major loops; 6 and sometimes 7 vehicles in Lane 1 of Loop 2; and 12 and sometimes 13 vehicles in Lane 2 of Loop 2. Finally, the daily driving schedule was increased to 19 hours and 5 minutes, with Sunday as an additional driving day.

Three rotating driving schedules applied test loads to the pavements during all hours of the day. Each schedule ran two separate 9.5-hour shifts, with drivers logging 7.5 hours of driving time per shift, after lunch and rest breaks. Much of the traffic operations took place at night, to allow a daily traffic break during daylight for maintenance and performance measurements.

The regular truck traffic ended November 30, 1960, producing 1,113,760 applications in each traffic lane for the 25-month period. A small transportation unit remained to conduct special tests at the site through the winter of 1960–1961 and into the spring.

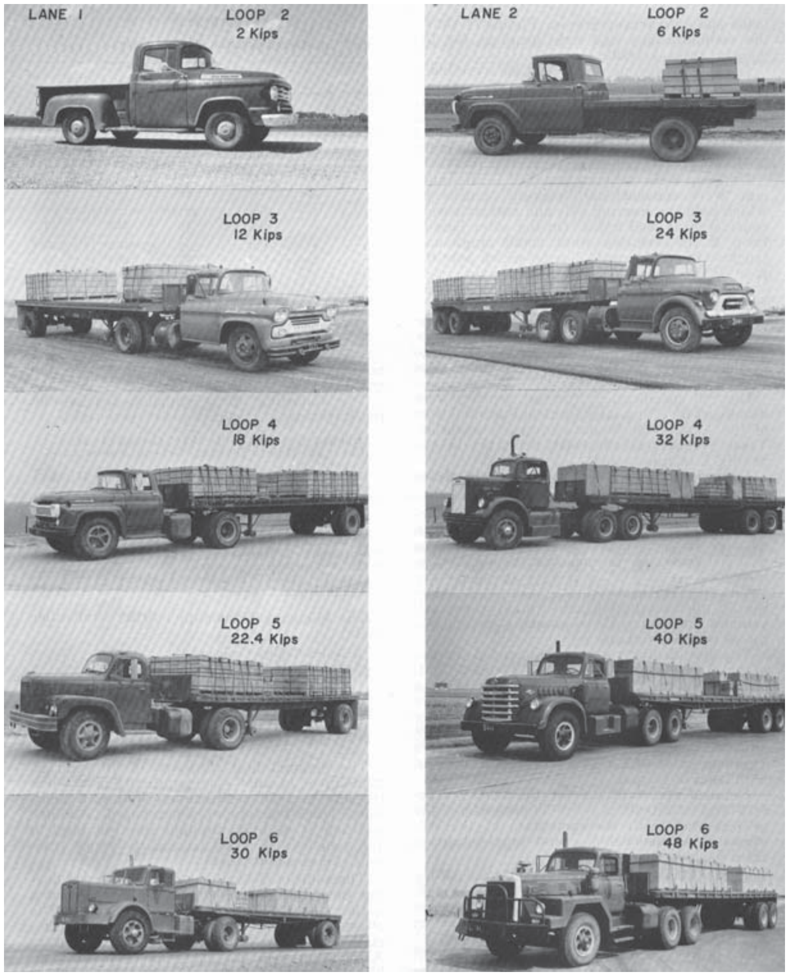


FIGURE 3 AASHO Road Test truck traffic.

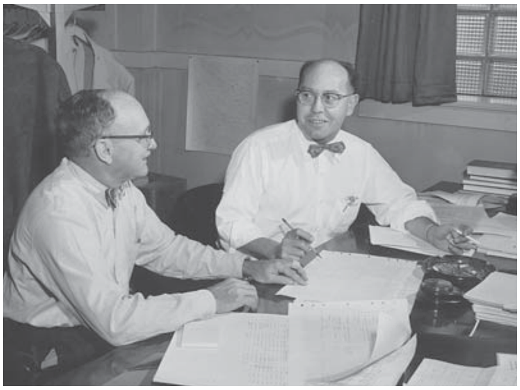
Maintenance

Because the Road Test focused on the performance of the test sections as constructed, maintenance operations were held to a minimum for any section still under study (*3*). When the serviceability of any section dropped to a specified level, the section was considered out of the test, and maintenance or reconstruction was performed as needed. Minor repairs, however, were made as required, regardless of the weather or the time of day.

Flexible pavement maintenance included fog seals, spot seals, skin patches, deep patches, and overlays. Rigid pavement maintenance included skin patches, joint and crack sealing, deep patches, and overlays. Other maintenance activities, such as shoulder maintenance, ditch and culvert cleaning, mowing, and snow and ice removal, were performed as needed.

Pavement Performance

The performance of the pavement sections was closely monitored. In general, measurements were made of variables that previous research had related to pave-



Alvin C. Benkelman, flexible pavement research engineer—inventor of the Benkelman beam for measuring road surface deflection—and Frank H. Scrivner, rigid pavement research engineer, discuss results in the Road Test field office, circa 1960.

ment performance. For flexible pavements, routine performance measures included longitudinal profile, roughness, cracking, patching, and rut depths; for rigid pavements, routine performance measures included longitudinal profile, cracking, patching, spalling, and joint or crack faulting.

The roughness and profile testing were conducted at 2-week intervals, but the other data were collected in weekly surveys. Other measurements, such as surface deflections, surface strains, vertical subgrade pressures, and pavement temperature distributions, were obtained at various times during the test.

Because a principal objective was to discover relationships between pavement performance and design variables, a rational method had to be developed to determine and express the performance of each pavement section (*5*). Carey and Paul Irick, Chief of Data Processing and Analysis, developed the concept of "pavement serviceability," founded on the principle that the primary function of a pavement is to serve the traveling public.

According to the principle, users of a pavement facility can provide subjective opinions about how well a pavement is meeting their needs, and the serviceability of a highway can be expressed as the mean evaluation of all highway users (*11*). Serviceability was rated on a scale of 0 to 5, with 0 representing a pavement that was impassable and 5 representing a perfectly smooth riding pavement.

Convening a panel of raters to provide opinions of road serviceability on the 800-plus Road Test pavement sections would have been impractical. An alternative means of assessing pavement serviceability was developed, relying on objective pavement condition measurements of roughness and distress on the test sections. With these objective measures, plus models developed from a panel review of pavements in Illinois, Minnesota, and Indiana, a "present serviceability index" was computed to estimate the mean panel serviceability rating for each section.

Performance Models

After completing the regular truck traffic operations in November 1960, researchers began to analyze the data and to develop relationships between pavement performance and pavement design and load variables. A single general model was selected for the pavement analysis, and then specific models were developed for each pavement type. Extended models were developed later to account for different subgrade support conditions, material properties, and climatic conditions.

HRB prepared an interim guide for the design of flexible and rigid pavements, featuring performance equations and nomographs to determine pavement thicknesses. The guide was submitted to the states in February 1962 for a 1-year trial. After the trial, the AASHO Design Committee decided to retain the guide as an interim document without revision.

The guide was reissued in 1972, with additional information, but still with interim status and with the basic design methods and procedures unchanged (*12*). A significantly revised design guide was released in 1986, incorporating many new considerations—such as design reliability, subgrade resilient modulus, and drainage—but still with the basic design models as the foundation. The current edition, released in 1993, presents further enhancements but remains indebted to the Road Test models.

Living Legacy

The AASHO Road Test continues to influence pavement engineering, and its legacy lives on in today's high-tech, computerized world. The researchers who contributed to the development, construction, and conduct of the AASHO Road Test may not have grasped the magnitude of the project's achievements. At the conclusion of the data analysis, the researchers cited the following as the main products of the Road Test (*1*):

- Serviceability–performance concept,
- Flexible and rigid pavement design equations,
- Load equivalency factors, and
- Single and tandem axle load equivalencies.

The researchers could not foresee the remarkable longevity of these products within the pavement community. The researchers also overlooked other significant results of the AASHO Road Test, including

- Quantification of the variability in pavement construction—and the resultant push toward statistical sampling measures;

Withstanding the Test of Time

FRED N. FINN, NAE

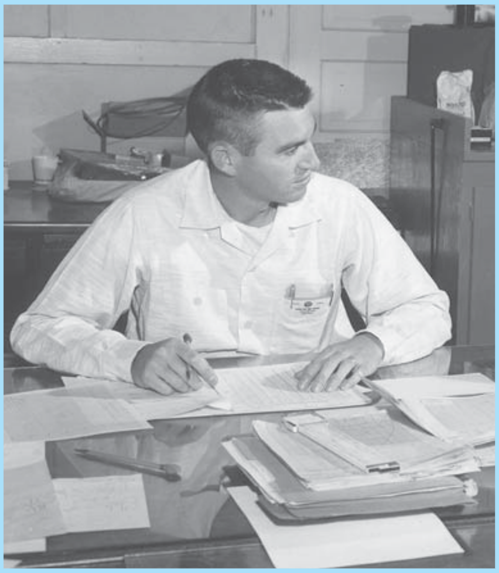
By any standard, the American Association of State Highway Officials (AASHO) Road Test was a remarkable engineering achievement. Road Test results that remain in effect and that probably will continue as basic tenets of pavement design include the following:

- Measuring pavement performance in terms of riding comfort;
- Addressing mixed traffic loads and configurations with a single design parameter;
- Considering the contributions of structural materials to performance;
- Measuring stress, strain, and deformation for application to analytical models;
- Understanding the influence of speed on pavement response;
- Using statistics in designing experiments and in analyzing data; and
- Predicting roadway performance from physical characteristics and traffic.

All of these approaches carry the trademark of the AASHO Road Test.

Why was this project so successful and why has it withstood the test of time? How has the information been adapted for application, despite the project's recognized constraints? As the Asphalt Institute's representative at the Road Test from 1956 through 1960, I participated in many phases of project construction and testing, and I attended meetings of the National Advisory Committee and the special advisory panels. Following are my perspectives on the Road Test's enduring legacy:

- The project was successful largely because of the participation and support of the states through AASHO, of the federal government, and of industry. Moreover, the Highway Research Board assembled a remarkable senior staff. The project goals were well defined, and a "can do" spirit prevailed among the professional staff and technicians.
- The results and findings have stood the test of time because of good planning by the on-site staff in determining the types and amounts of data needed for analysis. Various advisory panels also provided guidance. Moreover, the reports issued after completion of the project were characterized by the transparency of the data and of the data analysis, and raw data were made available to agencies and organizations interested in further analysis and interpretation.
- The results of the Road Test have been and remain at the core of pavement design methods. State departments of transportation, the Federal Highway Administration, and industry have devoted considerable resources to extend the findings to specific design methods, despite the constraints of the project. Extrapolations have accounted for traffic applications over a longer design period, radically different environments, different materials and material properties, higher standards for construction, mixed traffic effects, and more. The broad base of research available in the United States and abroad has made such extrapolations not only possible but capable of passing the test of reasonableness when applied more universally. The 1993 American Association of State Highway and Transportation Officials' *Guide for the Design of Pavement Structures* indicates how research and experience can be combined with basic information from the Road Test to develop a useful design methodology.



Author Finn at work in the AASHO Road Test field office, circa 1960.

There may never be another AASHO Road Test, but it will be a long time before the concepts that were developed and proved along a 9-mile portion of what is I-80 near Ottawa, Illinois, will be forgotten. The AASHO Road Test stands as a landmark in the development of pavement technology and is a credit to those who had the foresight to plan, support, and complete a project of such size and complexity.

Smithsonian to Archive Road Test Records

LINDA MASON

The handwritten numbers evoke the painstaking diligence in collecting data during the AASHO Road Test. Penciled into small boxes, the numbers fill columns that march across pages so wide they must be folded back to fit into the binder. Nearly a dozen performance variables for two pavement types, 836 test sections, and 1.1 million test load applications over 2 years produce a lot of data. Recorded in the field and in labs, the numbers fill many pages in many binders.

The intention of preserving the data is evident from the trail of technology through the decades: field notebooks and data maps, microfilm, 9-track computer tape, punch cards, and recently a digital version. Images also were preserved: five boxes of photographs, glass slides, and color transparencies of pavement sections and test procedures, of trucks and the soldiers who drove them, and of white-shirted men in fedoras posing for mouse-eared motion picture cameras.

Several generations of research managers have wondered how to safeguard access to the data and artifacts. An answer is at hand. The Smithsonian Institution's National Museum of American History will house the AASHO Road Test collection in its Archives Center in Washington, D.C. The materials will be included in the Smithsonian's online catalog and will be available for scholarly research by request at the Center. The collection could become part of a future exhibit.

Army researcher carefully records data now to be housed in Smithsonian for ongoing research.

Access to the collection is important because many of the data maps were lost in converting from one technology to another. As a result, the raw data from the tests must be matched up again with the column headings—a time-consuming project for which funding is not available. The Smithsonian will keep the collection intact and accessible, so that the opportunity to complete the restoration will not be lost.

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- The implementation of statistically based experimental design principles;
- The introduction of statistically based modeling procedures;
- The development and implementation of new pavement performance measuring equipment; and
- The framework for pavement and asset management.

Identifying the single most important benefit from the AASHO Road Test is difficult. The contributions to the design and construction of the nation's highways for nearly 50 years, however, are undeniable. The AASHO Road Test will continue to be recognized and remembered by pavement engineers and the transportation industry.

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TRANSIT COOPERATIVE RESEARCH PROGRAM REPORT

The New *Transit Capacity and Quality of Service Manual*

Tour of the Expanded Guide for Transit Planners and Operators

HERBERT S. LEVINSON

The author is a transportation consultant, New Haven, Connecticut, and an Icon Mentor, Urban Transportation Research Center, City College of New York. He is a member of the National Academy of Engineering, as well as the TRB Executive Committee; the Transit Cooperative Research Program Panel on Development of Transit Capacity and Quality of Service Principles, Practices, and Procedures; and the TRB Transit Capacity and Quality of Service Committee.

Publication of the second edition of the *Transit Capacity and Quality of Service Manual* (TCQSM), Transit Cooperative Research Program (TCRP) Report 100, concludes more than a decade of effort. The comprehensive document assembles a range of information and procedures to aid transit planners, operators, and researchers. The 572-page book with CD-ROM is a companion to TRB's renowned reference, the *Highway Capacity Manual*.

Guidance, Not Standards

The new TCQSM provides a consistent set of techniques and procedures for evaluating the quality of service and the capacity of transit services, facilities, and systems. The manual covers all types of public transportation—buses, rail transit, ferries, and terminals—and provides planning and operational techniques, along with syntheses of ridership and demands.

The new edition adds quality of service indices for urban fixed-route and demand-responsive

A transit system that uses manual on-board fare collection and restricts boardings to driver-attended doors, like this one in Cleveland, Ohio, cannot achieve its maximum capacity.

The Transit Capacity Concept Emerges

The concept of transit capacity predates the concept of highway capacity. The concept of transit capacity emerged during rail transit development in American and West European cities at the start of the 20th century.

A 1902 study of Chicago's Loop elevated railway found that "the station platforms on the Loop and not the junctions … limit the number of trains that can be operated over its tracks." The overlapping block signal system for New York City's first subway in 1904 was designed to achieve headways of 78 to 96 seconds between trains at 25 miles per hour.

Highway capacity, of course, was an early focus of the Highway Research Board. The Bureau of Public Roads—predecessor to the Federal Highway Administration—prepared the first *Highway Capacity Manual* (HCM) in 1950, and the TRB Highway Capacity and Quality of Service Committee—which included a Transit Systems Subcommittee— produced the subsequent editions in 1965, 1985, 1994, 1997, and 2000.

In a 1961 progress report, the Transit Systems Subcommittee presented information on passenger service times and transit capacity. The 1965 HCM suggested that the minimum headway between buses at a curbside bus stop should be twice the average dwell time, to account for variations. *Bus Use of Highways: State of the Art and Bus Use of Highways: Planning and Design Guidelines*, National Cooperative Highway Research Program Reports 143 and 155, respectively, described the basic relationships for bus transit capacity. The procedures were refined and included in the transit capacity chapter of the HCM in 1985 and 1994.

Most transit operators and planners, however, were not aware of the HCM materials. With encouragement from the Federal Transit Administration, the Transit Subcommittee supported the development of a separate document. Two studies emerged: *Rail Transit Capacity*, TCRP Report 13 (1996), and *Operational Analysis of Bus Lanes on Arterials*, TCRP Report 26 (1997). The first *Transit Capacity and Quality of Service Manual,* TCRP Web Document 6 (1999), drew on and expanded these interim reports.

transit. TCQSM brings together quality of service procedures and guidelines from a passenger's perspective, along with procedures to estimate transit vehicle capacity and person capacity.

The manual provides guidance but does not set standards. Setting standards for the amount or level of service that should be provided for a specific situation is the prerogative of individual transit agencies, which should take into account local characteristics and available resources.

Coverage

The TCQSM consists of nine parts:

1. **Introduction and Concepts** summarizes the content and intended application of the manual and presents an overview of transit quality of service and capacity.
2. **Transit in North America** describes transit modes, services, and facilities in the United States and Canada.
3. **Quality of Service** identifies the influences on passenger perceptions of the quality of transit travel and presents methods for quantitative evaluations. This chapter is an important addition to the literature on transit planning and operations.
4. **Bus Transit Capacity** provides procedures for evaluating the capacity of bus loading areas or berths, stops, and facilities, including transitways, high-occupancy vehicle lanes, arterial street bus lanes, and mixed traffic flow.
5. **Rail Transit Capacity** presents general and detailed procedures for evaluating the capacity of heavy rail or rapid transit, light rail, commuter rail, automated guideway transit, and ropeways. The emphasis is on rapid transit capacity.
6. **Ferry Capacity** makes an important addition to the literature, addressing the capacity of passenger and automobile ferries, including capacity constraints at docks.
7. **Stop, Station, and Terminal Capacity** describes procedures for evaluating the capacity and the passenger comfort levels for various elements of bus stops, transit centers, transit stations, intermodal terminals, and similar facilities. The focus is on passenger space and on designs that match platform and station access capacity.
8. **Glossary** defines a comprehensive list of transit industry terms.
9. **Index** locates key concepts and details in the text.

Quality of Service

The quality of service guidelines are an innovative feature of the manual. Defined as "the overall measured or perceived performance of transit service from the passenger's point of view," quality of service reflects the kinds of decisions that a potential passenger makes in deciding whether to use transit or another mode—usually a private automobile. The decision process has two parts:

At the multiple platform commuter rail terminal in Philadelphia, trains do not block others while passenger activity takes place.

1. Assessing whether transit is available, and if it is,

2. Comparing the comfort and convenience of transit with competing modes.

The quality of service measures reflect these two aspects of transit service, which apply to all transit systems in all communities. In contrast, transit capacity issues are mainly a concern in larger cities.

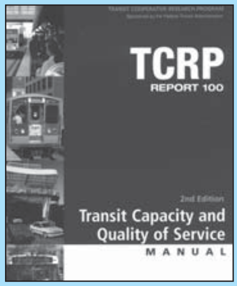
The measures differ from traditional highway quality of service measures, which are vehicle-oriented, and from the utilization and economic performance measures that the transit industry routinely collects, which tend to reflect the transit operator's point of view. Table 1 shows the overall quality of service framework for fixed-route and demand-responsive transit service.

Quality of service ratings—A to F for fixed-route services and 1 to 8 for demand-responsive services—are developed for each service measure, to reflect the differences in service quality experienced by passengers. The service measures can apply to quality of service for a transit stop, route segment, or system, or can be combined into a transit report card for an expanded perspective. The availability measures, as well as the travel time measures, are suited to short- and long-term planning; the comfort and convenience measures in each framework are suited for monitoring service delivery and changes.

For example, a fixed-route service at Level A for frequency would operate more than 6 vehicles per hour at headways—that is, time intervals—of less than 10 minutes, so that passengers would not need schedules. Other areas rated are hours of service, service coverage area, passenger load, on-time performance, headway adherence, and travel time compared with that in an automobile.

The quality of service and capacity values in the manual apply to conditions in the United States and Canada. Application to other countries would require recalibration of the parameters and the default values.

Problem-Solving Tool



Transit capacity is important in large cities—most people enter or leave the city centers by public transport. Quality of service measures provide a way to assess the importance of transit service availability and convenience for any city.

The *Transit Capacity and Quality of Service Manual*, 2nd Edition offers procedures to determine

- The types and sizes of the transit facilities needed;
- How well a transit line or system works and what improvements may be necessary; and
- How many transit vehicles are needed to serve the ridership demand.

Transit System Tasks

Although transit capacity concerns are mainly associated with large city systems, smaller systems may experience capacity problems when routes converge in or near a city center. Speed and reliability also are reduced when more than half of a bus facility's capacity is scheduled.

Transit agencies and transportation planners should recognize the following tasks:

- Understanding the influence of transit capacity on speed and reliability;
- Managing passenger loads—for example, determining how many buses or train cars are needed to accommodate the riders;
- Estimating the effect of changes in fare collection procedures, vehicle types and configurations, or other agency decisions—for example, changing from standard to articulated buses;
- Planning;
- Analyzing the operation of bus lanes and bus streets, as well as the areas around transit centers;
- Providing services for special events; and
- Establishing transportation system management policies.

TABLE 1 Quality of Service Framework

Fixed-Route Transit Service Measures			
	Transit Stop	**Route Segment**	**System**
Availability	Frequency	Hours of service	Service coverage
Comfort and Convenience	Passenger load	Reliability	Transit vs. automobile travel time
Demand-Responsive Transit Service Measures			
	Transit Stop	**Route Segment**	**System**
Availability	Response time	Span of service	
Comfort and Convenience	On-time performance	Trips not served	Demand-responsive transit vs. automobile travel time

Intermodal terminals, like Grand Central in New York, are designed for transfers between modes and have high passenger volumes.

Transit Capacity

Transit capacity deals with the movement of vehicles and of people.

◆ The *person capacity* of a transit route or facility is "the maximum number of people that can be carried past a given location during a given time period under specified operating conditions, without unreasonable delay, hazard, or restriction, and with reasonable certainty."

◆ The *vehicle capacity* of a transit route or facility is "the maximum number of transit vehicles (buses, trains, vessels, etc.) that can pass a given location during a given time period," usually 1 hour.

Vehicle capacity depends on the minimum possible headway between individual vehicles. The minimum headway depends on control systems such as traffic lights or train signals, passenger boarding and alighting demand at busy stops, and interactions with other vehicles.

In many cases, the vehicle capacity of a transit route will not be achieved, either because of resource limitations—for example, not enough transit vehicles available to reach maximum capacity—or because passenger demand may not justify operation at capacity.

Transit capacity can be measured along the way—way capacity—or at stops and terminals—station capacity. Capacities at major stops or terminals govern the achievable line capacities. Junctions near stations also can limit capacities. The minimum headway along a route governs the route's capacity.

Capacity Influences

The major influences on transit capacity are shown in Table 2, including vehicle, right-of-way, stop, operating, passenger, and street traffic characteristics. Transit vehicle capacity in units per hour depends on the

◆ Number of vehicles per unit—for example, cars per train;

◆ Minimum spacing between individual trains,

TABLE 2 Factors That Influence Transit Capacity

Vehicle Characteristics	
◆ Allowable number of units per vehicle (i.e., single-unit bus or multiple-car train)	◆ Number and height of steps
◆ Vehicle dimensions	◆ Maximum speed
◆ Seating configuration and capacity	◆ Acceleration and deceleration rates
◆ Number of wheelchair securement positions	◆ Type of door opening mechanism
	◆ Number, location, and width of doors
Right-of-Way Characteristics	
◆ Cross-section design (number of lanes, tracks)	◆ Intersection design and control
◆ Degree of separation from other traffic	◆ Horizontal and vertical alignment
Stop Characteristics	
◆ Amount of time stopped	◆ Fare collection method
◆ Stop spacing	◆ Type of fare
◆ Platform height vs. vehicle floor height	◆ Common vs. separate boarding or alighting areas
◆ Number and length of loading positions	◆ Passenger access to stops
Operating Characteristics	
◆ Intercity vs. suburban operations at terminals	◆ Time losses to obtain clock headways, provide driver relief
◆ Layover and schedule adjustment practices	◆ Regularity of arrivals at a given stop
Passenger Traffic Characteristics	
◆ Passenger concentrations and distribution at major stops	◆ Ridership peaking characteristics
Street Traffic Characteristics	
◆ Volume and nature of other traffic	◆ Presence of at-grade intersections
Method of Headway Control	
◆ Automatic or by train operator	◆ Policy spacing between vehicles

buses, or ferries—determined by the size of the unit, the clearance times between successive units, and the dwell times at the busiest stations or junctions;

◆ Number of bus berths, ferry docks, or rail station track platforms; and

◆ Available green time for movement in seconds per hour (3,600 seconds per hour for rapid transit, less than that for street running).

Transit passenger capacity depends on vehicle size and seating configuration. The “crush” capacity reflects the maximum possible number of passengers; most transit systems, however, use schedule design capacities, which are somewhat lower than the crush capacity.

The load factor in terms of passengers per seat is at best an approximation. The passenger spaces per vehicle consist of the number of seats plus the net remaining area, divided by the designated square feet per passenger. The schedule design and crush loads vary among transit agencies. For rail lines, schedule design loads range from 3 to 5.4 square feet per person; crush loads are about 2.8 square feet per person.

Learning from Equations

The basic capacity equations presented in TCQSM indicate the following:

◆ Capacity increases with more green time for vehicle movement, more passengers per vehicle, and more vehicles per unit.

◆ Capacity increases as the number of berths or track platforms increases; however, doubling the number of tracks or berths at a stop usually will result in less than double the capacity.

◆ Capacities vary inversely with the minimum headway between trains and buses. The headways depend on dwell times, variations in the dwell times, and the required clearance times between successive trains or buses.

◆ Capacities are reduced when dwell times at major stops are unduly long.

Assessing Capacity

The following considerations are important in assessing the capacity of a transit stop or route:

◆ The peak ridership demand in the maximum load section of a transit line determines the desired service frequency. This frequency should be accommodated at the busiest stops.

◆ The number of trains or buses that can be accommodated per hour decreases as the number of passengers per train or bus increases, because more time is required at stops.

Boarding islands allow bus stops to be located between travel lanes so that buses can use a faster lane without having to merge into the right lane before every stop.

◆ When trains operate at crush loads, the throughput in people per hour can be less than when car loads are lighter.

◆ A transit line that has a relatively uniform distribution of boarding passengers among stops usually will have a higher capacity than a transit line with passenger boardings concentrated at a single stop.

◆ The maximum rate of passenger flow is constrained by acceptable levels of passenger comfort, the presence of other traffic sharing the right-of-way, and safety considerations.

◆ Operating at capacity tends to strain transit systems, creating vehicle bunching and passenger delays—conditions that should be avoided. For example, when a bus berth operates at 75 percent of capacity, speeds are reduced 14 percent by bus-to-bus interference; at 100 percent of capacity, however, speeds are cut in half.

◆ Because capacity relates closely to system performance and service quality in terms of speed, comfort, and service reliability, a single fixed number can be misleading.

◆ Volume-to-capacity comparisons should use peak 15-minute passenger flow rates.

◆ The reasonableness of capacities obtained by analytical methods must be cross-checked against operating experience.

Many light rail lines are not signaled with the minimum possible headway in mind, but more economically for the minimum planned headway.

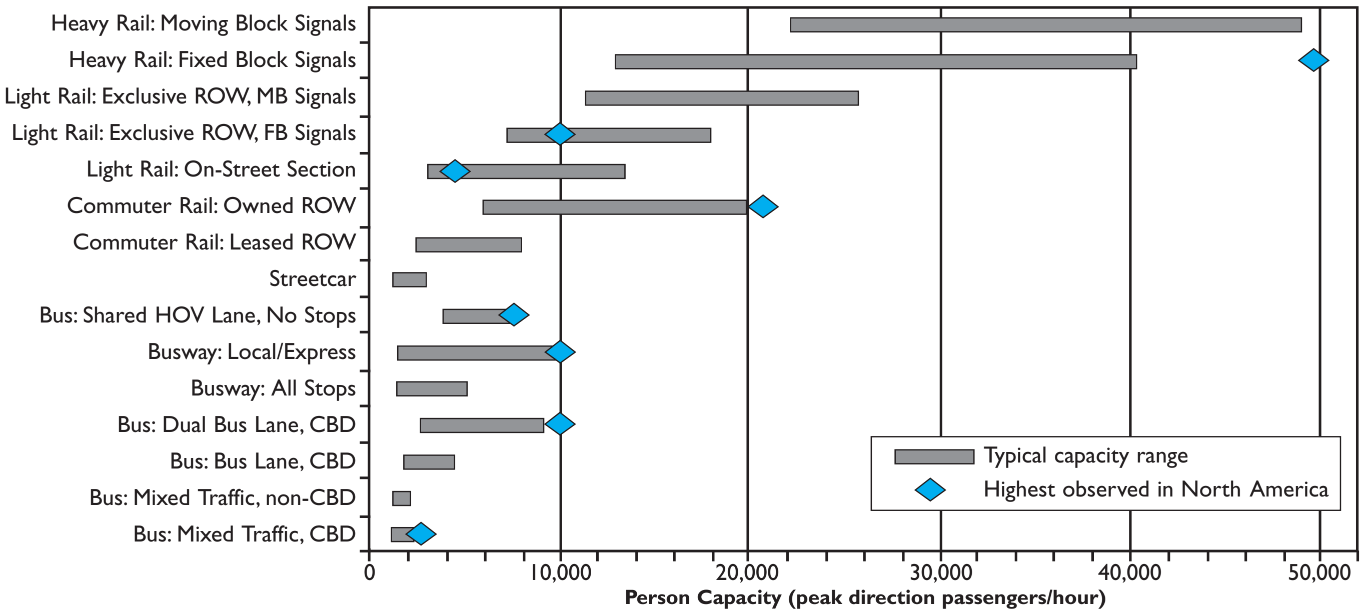


FIGURE 1 Person capacity ranges of U.S. and Canadian transit modes.
(ROW = right-of-way; MB = moving block; FB = fixed block; CBD = central business district.)

Operating Experience

The TCQSM contains a wealth of information on vehicle and passenger capacities in the United States and Canada. Figure 1 shows the person capacities for modes and facility types. The ranges reflect differing assumptions about the number of cars per train, dwell times, and so on. Rail values represent persons per track per hour. HOV lane volumes assume shared use with car pools.

The person capacities reflect the upper limit of crowding that North Americans will accept. Higher person capacities are achieved in other parts of the world that accept higher levels of crowding. Figure 1 also indicates the maximum passenger volumes observed in North America.

Productive capacity is the passenger capacity multiplied by the speed of a transit line. Figure 2 shows typical productive capacity ranges for transit modes

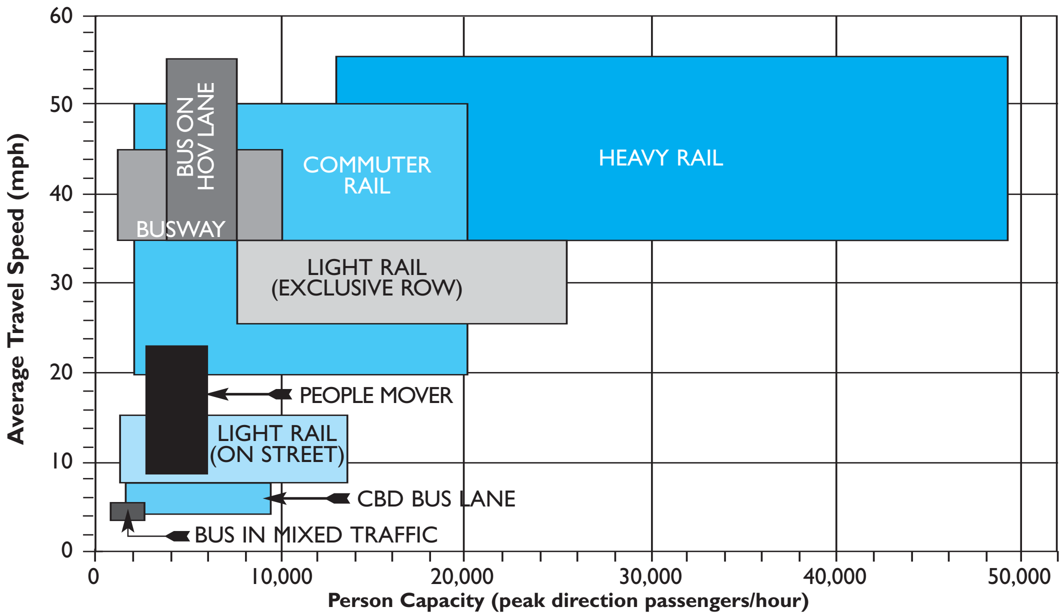


FIGURE 2 Typical travel speed and capacity ranges of U.S. and Canadian transit modes. (HOV = high-occupancy vehicle.)

on different types of facilities. The travel speeds include stops; and the speed ranges reflect differences in average stop spacing, dwell times, route geometry, traffic congestion, and other factors.

Bus Transit

The highest bus volumes in North America are on the Lincoln Tunnel approach to the 210-berth Port Authority Midtown Bus Terminal in Manhattan. Approximately 735 buses carrying 33,000 people per hour operate nonstop in exclusive bus lanes and bus-only ramps.

If bus stops or layovers are required, bus volumes decrease. Exclusive busways with passing capabilities at stations—like those in Ottawa, Ontario—can carry more than 10,000 people on 200 buses per hour in one direction. Dual bus lanes on city streets—such as along Madison Avenue in Manhattan, and the Fifth and Sixth Avenue Transit Malls in Portland, Oregon—also achieve this flow rate.

Bus lanes on downtown streets generally carry 80 to 120 buses per hour, if each stop has several loading areas and if passenger boardings are dispersed. These bus volumes correspond to 5,000 to 7,500 passengers per hour, depending on passenger loads.

Portland, Oregon, operates a light rail transit line on a mixed traffic–curb lane right-of-way.

Transit Capacity and Quality of Service Manual, 2nd Edition

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Rail Transit

Rail rapid transit lines carry 25,000 to 30,000 people per track per hour, with the higher volumes achieved on a few lines in New York City. Rapid transit lines typically operate a maximum of 25 to 30 trains per track per hour; exceptions are lines in Moscow, Paris, St. Petersburg, São Paulo, Tokyo, and Hong Kong, which run on headways of 90 to 115 seconds.

Achieving a 2-minute headway for 600-foot, 8- to 10-car trains requires dwell times of less than 30 seconds, stations at least 3/8 of a mile apart, a maximum of one merge, grades of 3 percent or less, radii of at least 600 feet, and adequate terminals. Commuter rail lines entering New York City from the north, east, and west carry about 20,000 passengers per track per hour. Throughput is influenced by "reverse running"—reversing a track in the heavy direction of travel—and by the availability of platforms at terminals.

Light rail lines can carry approximately 20,000 people per track per hour. Most light rail lines in North America, however, carry less than 10,000 people per hour—Boston's Green Line carries this amount on two tracks. Most systems have peak-hour flows of less than 5,000 passengers. Except for street cars in Philadelphia and Toronto, light rail lines generally operate fewer than 30 trains per track per hour.

Rail transit route structures with fewer branches achieve lower headways and higher capacities. Track and storage space at terminals helps avoid bottlenecks when turning trains around or laying them over. Increasing the car length without increasing door space can create problems—Hong

A Portland, Oregon, bus stops in the traffic lane to load and unload riders, called *on-line* loading. The clearance time—the amount of time needed for a bus to clear the stop—differs between *on-line* and *off-line* loading. In *off-line* loading, buses stop out of traffic and must wait for a suitable gap in traffic before re-entering.

Kong's 75-foot cars have 5 doors per side and process passengers faster than New York City cars with only 4 doors per side.

Analysis Procedures

The TCQSM contains detailed analyses, computational procedures, and sample problems for each type of public transport. Brief samples follow.

Bus

The manual provides the basic equation for determining loading-area vehicle capacity. Exhibits show the capacity at a single on-line stop and provide a tool for calculating capacity for stops with several berths. Person capacities are calculated by multiplying the number of buses per hour by the average maximum scheduled load per bus—for example, 60 passengers for a standard 40-foot bus or 90 to 100 passengers for an articulated bus—and multiplying again by a peak hour factor that reflects the peak 15-minute passenger volumes.

Rail

The TCQSM sets forth procedures for grade-separated rail, light rail, commuter rail, and automatic guideway transit. A series of equations, keyed to the dynamics of movement, is presented for conventional block signals, fixed-block cab signals, moving blocks, turn-backs at terminals, flat junctions, and single-track operations.

The minimum train operating headway is a function of

- The type and characteristics of the signal system, including block lengths and separation;

Multiple loading areas at the South East Busway in Brisbane, Australia.

- The operating speed at station approaches and exits or at other bottlenecks, such as junctions; and
- The train length and the station dwell times.

Applying these procedures to a 660-foot, 8- to 10- car train produces the following headways with a 45-second dwell time:

- Three-aspect system, 122 seconds;
- Cab-control system, 116 seconds; and
- Moving block system with variable stopping distance, 102 seconds.

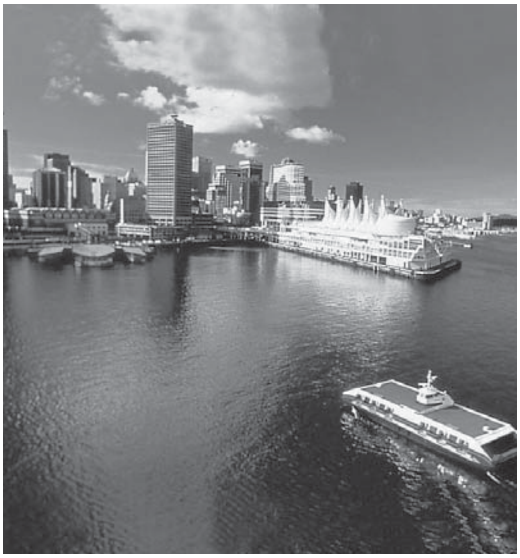
The operating results for moving block signal controls, however, remain to be documented.

For light rail systems that operate on exclusive rights-of-way, procedures for heavy rail can be used, taking into account the shorter train lengths. The bus capacity equation can apply to street running, with adjustments for the longer clearance times needed; in addition, it is desirable to operate trains every other signal cycle to minimize possible spillback. For a 90-second cycle, for example, the limit would be 20 trains per track per hour.

Space requirements for U.S. and Canadian rapid transit or heavy rail cars range from about 2.1 to 3.5 passengers per foot of car length. The higher end of this range approaches crush load conditions. The lower end of this range, at 2.1 to 2.4 passengers per foot of length, with a standing space per passenger of 4.3 to 3.2 square feet, is an appropriate, yet tight, range for higher-use systems. New York City, for instance, uses a schedule design loading of 3 square feet per passenger on busy lines.

The Siemens-Düwag car used in nine light rail systems (with some dimensional changes) ranges from 1.5 to 2.4 passengers per foot of car length. The lower level of 1.5 passengers per foot of length with a standing space per passenger of 4.3 square feet corresponds closely with the recommended comfortable loading of 5.4 square feet per passenger.

Platform traffic in Portland, Oregon.



Harbor point-to-point ferry service in Vancouver, Canada.

When designing for a new system, 5.4 square feet per passenger during the peak hour is appropriate for a higher—that is, more comfortable—level of service. This recommended passenger space corresponds to a linear loading level of 1.8 passengers per foot of length for heavy rail cars and 1.5 passengers per foot of length for narrower light rail cars.

Ferries

A new chapter reviews the capacities of passenger and automobile ferries. Ferry berth or loading area capacities are a function of arrival service time, which consists of disembarking time plus clearance time, and departure service time, which consists of embarking time plus clearance time. Passenger demand, fare payment or ticket collection, and facilities affect embarking and disembarking times, and gangway technology, mooring procedures, and harbor traffic affect clearance time. The TCQSM shows how to key these data to vessels of varying size to estimate the passenger capacity of a ferry loading area.

Updating the Manual

The TCQSM is a living document, which will be reviewed and updated continuously by the TRB Committee on Transit Capacity and Quality of Service. Continued liaison with transit agencies will be an integral part of this continuing effort. User comments are welcome and can be made via the committee's website at http://webboard.TRB.org/~tcqsm.

To order the TCQSM, visit the online TRB Bookstore, www.TRB.org/bookstore/, or call 202-334-3213.

CALENDAR

TRB Meetings 2004

July

14–17 Geometric Design Midyear Meeting and Workshop
Williamsburg, Virginia

18–20 Management and Productivity Summer 2004 Conference
Woods Hole, Massachusetts
Claire Felbinger

18–21 43rd Annual Workshop on Transportation Law
Savannah, Georgia
James McDaniel

20–21 Workshop on Research Needed to Support Vehicle-Infrastructure Cooperation
Detroit, Michigan
Richard Cunard

21–24 Highway Capacity and Quality of Service Committee Midyear Meeting and Conference
State College, Pennsylvania
Richard Cunard

25–27 Joint Summer Meeting of the Planning, Economics, Environmental, Finance, Freight, and Management Committees
Park City, Utah
Elaine King

August

2–4 Removing Water from Within Pavement Structures*
Sacramento, California

12 Workshop on Transit Capacity and Quality of Service
Vancouver, British Columbia, Canada
Peter Shaw

21–26 National Community Impact Assessment Conference*
Portland, Maine
Claire Felbinger

22–24 Performance Measures to Improve Transportation Systems: 2nd National Conference
Irvine, California
Kimberly Fisher

29–Sept. 1 6th National Meeting on Access Management
Kansas City, Missouri
Kimberly Fisher

September

7 Geotechnical Methods Revisited
Kansas City, Missouri
G.P. Jayaprakash

7–10 Pro Walk–Pro Bike*
Victoria, British Columbia, Canada
Richard Pain

8 Creating Rural Freight Transport Opportunities in a Global Market*
Minneapolis, Minnesota
Joedy Cambridge

12–15 North American Conference on Elderly Mobility: Best Practices from Around the World*
Detroit, Michigan
Richard Pain

14–17 Structural Materials Technology: Nondestructive Evaluation–Nondestructive Test for Highways and Bridges*
Buffalo, New York
Stephen Maher

22–24 9th National Conference on Transportation Planning for Small and Medium-Sized Communities: Tools of the Trade
Colorado Springs, Colorado
Kimberly Fisher

26–29 2nd International Conference on Accelerated Pavement Testing*
Minneapolis, Minnesota
Stephen Maher

October

19–22 2nd International Conference on Bridge Maintenance, Safety, and Management*
Kyoto, Japan

19–24 6th International Conference on Managing Pavements*
Brisbane, Queensland, Australia
Stephen Maher

24–27 16th National Rural Public and Intercity Bus Transportation: Celebrating the Silver—Going for the Gold
Roanoke, Virginia
Peter Shaw

24–27 14th Equipment Management Workshop
Minneapolis, Minnesota

26–27 Future Truck and Bus Safety Research Opportunities Conference
Washington, D.C.
Richard Pain

November

1–2 National Household Travel Survey Conference: Understanding Our Nation's Travel
Washington, D.C.
Tom Palmerlee

16–17 7th Marine Transportation System Research and Technology Coordination Conference
Washington, D.C.
Joedy Cambridge

18–20 Conference for Research on Women's Transportation Issues
Chicago, Illinois
Elaine King, Kimberly Fisher

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 (www.TRB.org/calendar). 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, or e-mail lkarson@nas.edu/. Meeting listings without TRB staff contacts have direct links from the TRB calendar web page.

*TRB is cosponsor of the meeting.

TRB SPECIAL REPORT

Buckling Up

Technologies to Increase Seat Belt Use

NANCY P. HUMPHREY

Using seat belts is one of the most effective strategies available to the driving public for avoiding death and injury in a crash. Today, however, nearly 35 years since the federal government required that all passenger cars be equipped with seat belts, approximately one-quarter of U.S. drivers and front-seat passengers are not buckling up.[1] Belt use rates in the United States lag well behind the 90 to 95 percent usage rates in Canada, Australia, and several northern European countries.

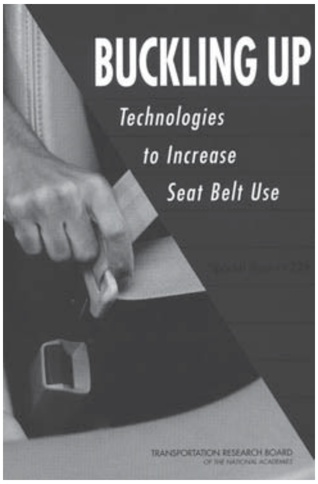
Properly used, seat belts can reduce the risk of fatal injury for front-seat occupants by about 45 percent in cars and by about 60 percent in light trucks driven as passenger vehicles. According to the National Highway Traffic Safety Administration (NHTSA), each percentage point increase in belt use should result in an estimated 250 lives saved per year.

[1] Statistics cited in this article were valid in 2003, when the study was completed.

Study Charge

Congress requested that the National Research Council (NRC) of the National Academies conduct a study to examine the potential benefits and public acceptability of technologies to boost seat belt use, such as reminder systems that exceed regulatory requirements. Under the auspices of the Transportation Research Board, NRC convened an expert committee (see box, page 37) to carry out the study, which was funded by NHTSA.

The committee's findings and recommendations, published in Special Report 278, *Buckling Up: Technologies to Increase Seat Belt Use*, include legislative and regulatory actions to enable installation of effective and acceptable new belt use reminder technologies in passenger vehicles.



TRB Special Report 278, *Buckling Up: Technologies to Increase Seat Belt Use*, is available from the online TRB Bookstore, www.TRB.org/bookstore/. (View the book online, www.TRB.org/publications/sr/sr278.pdf.)

Past Strategies

The requirement to install lap and shoulder belts in all new passenger vehicles was one of the original standards stemming from federal legislation in 1960 to improve highway safety. The availability of belts, however, was not enough to motivate use by drivers and passengers. Few motorists—perhaps only 10 to 15 percent—buckled up voluntarily.

A new agency then, NHTSA began promoting airbags, automatic belt systems, and 60-second flashing light and buzzer warnings to remind motorists to buckle up. Technical and political factors, however, delayed the introduction of airbags and automatic belts. As an interim measure, NHTSA mandated that all model year (MY) 1974 passenger vehicles be equipped with an ignition interlock to prevent the engine from starting if any front-seat occupant was not buckled up.

The ignition interlock requirement, however, met with strong opposition for a variety of reasons, including belt comfort, sensor accuracy, and public acceptance. Congress promptly enacted legislation prohibiting NHTSA from requiring either ignition interlocks or continuous buzzer warnings of more than 8 seconds. NHTSA then implemented the requirement of a 4- to 8-second warning light and buzzer system that is activated when front seat belts are not fastened at the time of ignition. This standard remains in effect.

NHTSA subsequently focused on restraint systems that required no action on the part of the motorist—such as air bags, which provide supplemental protection to seat belts. The agency also began strongly encouraging states to pass belt use laws. The laws were introduced rapidly and have contributed to sharp increases in belt use. Observed belt use rates today are approximately 75 percent. The rate of belt use gains, however, has slowed in the past decade.

Changing Nonusers

Many drivers and vehicle occupants report that they understand the safety benefits of belts, but that they have not acquired the habit of buckling up on all trips. For these part-time users, who constitute roughly one-fifth of drivers, belt use is situational—they tend to buckle up when the weather is poor or when they are taking longer trips on riskier, high-speed roads. The behavior of this group may be open to change through new reminder systems.

Hard-core nonusers comprise approximately 4 percent of drivers, but this same group has significantly more traffic violations, higher crash involvement rates, higher arrest rates, and higher rates of alcohol consumption than those who buckle up all or part of the time. Sixty percent of drivers in severe crashes were reportedly not wearing seat belts. These nonusers pose risks to themselves and to others and are therefore an important audience to reach; however, reminder systems may not be effective.

Technology Revisited

Federal law restricts NHTSA's regulatory scope in new seat belt use technologies, but manufacturers are not prevented from providing new technologies voluntarily. Ford Motor Company, for example, equipped selected MY 2000 vehicles with BeltMinder™, a system of warning chimes and flashing lights that operates intermittently for up to 5 minutes to alert and remind the unbelted driver to buckle up.

Many other companies plan to deploy enhanced belt reminder systems incorporating technologies that go beyond the current 4- to 8-second warning. No manufacturers are developing interlock systems as original equipment, although technologies such as a seat belt shifter lock—which prevents the changing of gears unless belts are buckled—soon may be available as an after-market option in the United States.

Today's environment is far more conducive than that of the early 1970s to the introduction of technologies for increasing seat belt use. Belt use is compulsory for adults in all but one state; belt use rates are significantly higher; belts are better designed; and sensing technologies are more sophisticated and reliable.

Nevertheless, the pace and type of technology introduction continue to be affected by the interlock experience. Industry is sensitive to consumer acceptance of what may be perceived as intrusive systems, and NHTSA's regulatory scope remains limited.

Findings

After reviewing the literature, as well as the results of in-depth interviews and focus groups conducted by NHTSA, and after briefings by industry and government officials, the committee concluded that new seat belt use technologies—particularly the enhanced belt reminder systems—have the potential to increase belt use and to be received favorably by most consumers. Part-time users, for example, apparently would welcome a reminder to buckle up.

More aggressive systems, such as transmission interlocks, probably would be necessary to reach hard-core nonusers, but the in-depth interviews and focus groups conducted for this study suggest that required interlocks would have a low acceptability. This suggests that interlocks should be considered only for certain high-risk drivers.

In addition, the legislation prohibiting NHTSA from requiring new seat belt use technologies is outdated and unnecessarily restrictive. Although industry is introducing new systems on some models, NHTSA does not have the legislative authority to establish minimum performance standards.

Recommendations

The committee's recommendations, briefly summarized below, are detailed in the full report. In general, the recommendations are designed to encourage and facilitate the installation of effective new seat belt use technologies.

The committee recommends that Congress amend the statutory restrictions on belt reminder systems immediately, providing NHTSA with more flexibility and authority to require effective belt reminder technologies, if necessary. Moreover, industry voluntarily should provide new systems in the front seats of every new light-duty passenger vehicle, and these systems should have audible and visible indicators that are not easily disconnected.

To ensure that the most effective systems are introduced, NHTSA should monitor and evaluate deployment closely. If industry does not move promptly, NHTSA should mandate the most effective acceptable systems and should conduct another independent review in 5 years to evaluate progress.

The recommended strategy includes a program of behavioral research and field testing to ensure that NHTSA can base any needed regulations on good science. Although the immediate emphasis is on front-seat reminder systems, aggressive development of effective rear-seat reminder systems also should be pursued.

Seat belt use technologies should be viewed as complements to other proven strategies for increasing belt use. These include enactment of primary seat belt use laws that enable police to pull over and cite drivers who are not buckled up, as well as publicly promoted enforcement programs.

Seat belt reminder systems may not be adequate for reaching hardcore nonusers. In the near term, NHTSA and the private sector should strongly encourage research and development of seat-belt interlock systems for specific applications. For example, the courts could require the use of interlocks for motorists convicted of driving impaired; parents could install interlocks on vehicles driven by teenagers; insurance companies could lower premium rates for young drivers of vehicles with interlock systems; and fleet owners could install interlocks.

If these efforts and the introduction of enhanced belt reminder systems fail to reach high-risk drivers, however, the issue of requiring interlocks should be revisited in a few years.

The author, Senior Program Officer in TRB's Division of Studies and Information Services, served as Study Director for this project.

Committee for the Safety Belt Technology Study

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TRB SPECIAL REPORT

Shipboard Automatic Identification System Displays

Meeting the Needs of Mariners

JOCELYN N. SANDS

A shipboard automatic identification system (AIS) automatically communicates information about a vessel's identification, position, course, and speed to other vessels and shore stations. AIS also facilitates the communication of vessel traffic management and navigational safety data from shore stations to vessels.

During the last two decades, much has been done to define the technical and communications requirements for AIS, but little effort has addressed the shipboard display of information. The world fleet of merchant vessels has begun to adopt the international carriage requirements, which specify the charts, publications, and equipment that must be on board. The requirements mandate AIS for ocean-going vessels under the International Convention for the Safety of Life at Sea (SOLAS). The United States Coast Guard (USCG) regulates AIS for vessels in U.S. waters and aboard U.S.-flag vessels.

To assist in developing AIS carriage requirements, USCG asked the Transportation Research Board (TRB)–Marine Board, through the National Research Council (NRC) of the National Academies, to assess the state of the art in AIS display technologies, evaluate system designs and capabilities, and review the human factors aspects of operating these systems. Consideration was to be given to the effects on shipboard AIS displays from

- Technology, security, economics, operating considerations, and human factors design;
- The range of tasks to be supported;
- Differences in operating environments and in qualifications and skills requirements;
- Changes in technology, equipment and technical integration, requirements for harmonizing with international standards, and requirements set by manufacturers and standards-making bodies; and
- Lessons learned and best practices from relevant domestic and international AIS programs.

Under the auspices of the TRB Marine Board, NRC assembled a committee of experts in instrumentation and electronic systems engineering, human factors, ship design and marine engineering, marine navigation and ship operations, and inland waterways operations (see box, page 41).

Photo: David Natali, Clipper Navigation, Inc.

Wheelhouse of high-speed ferry.

Identifying Concerns

The committee was asked to evaluate the state of the art for AIS displays, analyze current problems, and make recommendations to aid USCG in developing AIS standards and requirements. The committee reviewed a large amount of background information and conducted information-gathering sessions, including a workshop in New Orleans, Louisiana, and site visits to the United Kingdom, Germany, and Sweden.

The committee identified many concerns affecting the shipboard display of information. Some of the concerns are the result of AIS being in the early stages of implementation, and others stem from the issues of mariner workload and data management. Members of the committee noted that AIS data must be integrated carefully into the volume of information provided to mariners from a variety of sources, or much of the potential benefit from AIS could be lost.

These concerns are implicit in the committee's recommendations. The committee advises USCG to ensure that safety and human factors are priorities in the development of AIS regulations.

Systematic Implementation

Because of the complexity of implementing AIS aboard vessels, the committee finds that a systematic plan is needed. The plan would address assumptions about the types of onboard equipment to be integrated with AIS. For example, requirements are needed for integrating AIS information with information from other onboard electronic navigation systems. Additional work is needed to determine the best way to integrate current and new systems.

Recommendation 1: USCG should establish an implementation plan and schedule for AIS shipboard display standards in consultation with stakeholders. Key elements of the plan should include

- Research in technical and human factors,
- Determination and analysis of requirements, and
- Development of international and domestic standards.

AIS and Shipboard Displays

Although displays can be the means for converting AIS data into useful information for the operator, little has been done to define the information needs and priorities for display parameters. In the United States, AIS is in the early stages of implementation, and the technology is experimental or prototype.

Concerned that problems could result without the timely and prudent introduction of AIS displays, the committee advises that AIS displays should be introduced to meet the needs of mariners without adding a burden of inessential information.

AIS complements traditional aids to navigation but does not replace them. For example, AIS does not replace the need to establish vehicle position using all available means appropriate to the circumstances. The system should display three types of vessel-specific data: static information, dynamic information, and voyage-related information.

The International Maritime Organization (IMO) has defined three functions for AIS:

1. To assist in collision avoidance when operating in the ship-to-ship mode,
2. To provide information about a ship and its cargo to authorities on shore, and
3. To assist authorities in vessel traffic management.

To assist in collision avoidance, an AIS display should supply information directly to the mariner for maneuvering within close quarters or planning a meet-and-pass encounter. A shipboard display, however, probably would have little use in providing ship and cargo information to local authorities.

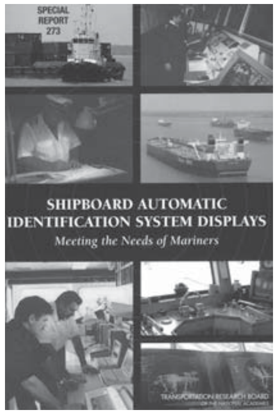
Operating Environment

Nonetheless, AIS can communicate a range of data to assist in vessel traffic management, and a shipboard display may have a significant role in this task, depending on the nature and design of the traffic management system. The relationships between AIS functions, information types, and data elements are summarized in Figure 1.

AIS information will be displayed in many different operating environments: rivers and inland waterways, high-density ports with mixed traffic, coastal waterways, urban harbors with scheduled ferry and passenger vessel operations, and major commercial ports accommodating large deep-sea vessels. In the United States, operators of tugs, towing vessels, passenger ferries, and other non-SOLAS vessels are most likely to be required to use AIS.

The operating environment will affect the configuration of the displays with which AIS must interface for proper operation. Many of these smaller domestic vessels, however, may not carry all of the equipment with which an AIS needs to interface for proper operation—they may carry none at all.

The majority of the large commercial vessels transiting U.S. waters are of foreign registry and are manned by a variety of nationalities. This complicates display issues because a common operating



TRB Special Report 273, *Shipboard Automatic Identification System Displays: Meeting the Needs of Mariners*, is available from the online TRB Bookstore, www.TRB.org/bookstore/. (View the book online, www.TRB.org/publications/sr/sr273.pdf.)

AIS Data Elements

Static	Dynamic	Voyage-related	Functions
Beam Length Antenna location	Navigational status Weather	Hazardous cargo Draft ETA* Route plan*	Vessel Traffic Management
Antenna location Length/beam	Course Heading Speed Position Rate of turn* Length/beam	Draft	Collision Avoidance
Vessel name Call sign/MMSI Type of ship/IMO# Cargo	Cargo on board	Cargo on board	Identification

Information Type

*Optional information

FIGURE 1 Representative AIS data elements, functions, and information.

environment must be established for mariners, independent of the area in which they are operating.

Carriage Requirements

Carriage equipment is designated as Class A, Class A derivative, or Class B. Class A units are for oceangoing vessels. Class A derivative units are portable carry-on units generally used by pilots in U.S. ports and waterways. Class B units have less stringent requirements and are intended for use by inland and coastal vessels.

Class A derivative units have received the most attention in the United States because they are similar to those that pilots have used as carry-aboard units. The definition, role, and display requirements for Class A derivative units, however, are incomplete. Class B units also are not well defined. More analysis of Class A derivatives and Class B is necessary before unit requirements can be specified.

The initial carriage requirements do not specify shipboard display for use by the mariner, except for the minimal, basic numerical identification data. The minimum keyboard and display (MKD)—a minimal numerical system—is used widely as a shipboard display but does not provide adequate information for the mariner and could be detrimental to safe vessel navigation. USCG therefore should establish new minimal display standards before MKD becomes the default standard for U.S. operations.

Taking the Lead

Recommendation 2: USCG should establish requirements for shipboard display of AIS information in navigable waters of the United States by

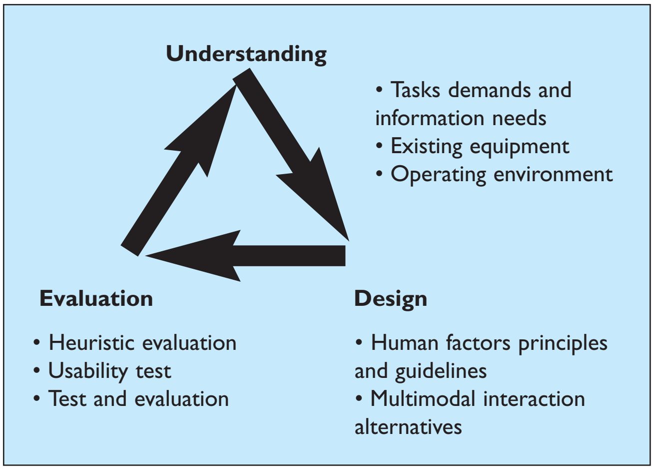


FIGURE 2 Iterative cycle of system development. (Adapted from Woods, D. D., E. S. Patterson, J. Corban, and J. C. Watts. Bridging the Gap Between User-Centered Intentions and Actual Design Practice. *Proc., 40th Annual Meeting*, Vol. 2, Human Factors and Ergonomics Society, Santa Monica, Calif., 1996, pp. 967–971.)

- Defining the information needs of mariners;
- Defining key functions for AIS displays aboard different types of vessels and in different operating environments;
- Developing appropriate requirements for each major vessel class, taking into consideration the differences in operating environments;
- Involving the key stakeholders in the entire process; and
- Developing a new requirement for minimum information display of AIS.

USCG should take the lead in establishing display requirements for AIS information and should work with appropriate international organizations to ensure compatibility with international requirements.

Recommendation 3: USCG should recognize the evolving nature of AIS display technology in its requirements process and allow for technological change, growth, and improvements.

Human Factors in Design

For AIS to promote safe vessel navigation, an effective onboard interface with the vessel's operator is essential. An interface should include both the display and the control mechanisms that allow the exchange of information between the operator and the rest of the system. Information may be displayed through such means as a cathode ray tube, graphics, auditory warnings, and data entry and through control elements such as keyboards or switches.

A typical iterative cycle of system development focusing on human factors is shown in Figure 2 :

1. *Understanding* the operational demands and the needs of the mariner. Advanced technology can increase errors and risk even when appearing beneficial.

2. *Initial design* incorporates the large body of knowledge about human factors interface. Human factors principles relevant to AIS interface design include ensuring that system behavior is completely visible to the operator, avoiding interface management tasks during high-tempo situations, and realizing that the representation of AIS data can greatly affect interpretations. Multimodal display alternatives should be considered in addition to graphics and text.

3. *Evaluation of the design.* The evaluation tests a design's performance and leads to adoption or redesign to correct a problem. A trial-and-error method, usability testing, and operational evaluation are complementary approaches to identifying problems.

Maritime technology and AIS applications are difficult to predict. USCG needs to allow designers the freedom to adapt to changes.

Recommendation 4: In its standards, USCG should specify that design, process, and performance standards be used in combination to promote adequate shipboard AIS displays.

System Limitations

The committee finds several limitations to AIS:

- The systems are not fail-safe. Equipment that is not operating onboard can drop out of use for surveillance. A decision to turn the equipment off or otherwise disable it also removes the vessel from the display.
- The integrity of the data that must be provided by the carrying vessel is not assured. Some data are manually entered by an operator and can be changed or could contain errors.
- Multiple shipboard sensors can produce multiple displays of single targets. The target ambiguity must be resolved through a sorting process not yet fully developed.

Further attention may need to be given to such issues as the system capacity for transmitting messages, transponder coverage and the spacing of shore-based repeater stations, the adequacy and accuracy of digital charting, the availability of vessel instrumentation, and the need for standardized interfaces between equipment.

Training will be needed. Stakeholders such as vessel operators, equipment manufacturers, and vessel traffic managers should be involved in developing training guidelines.

Recommendation 5: USCG should identify critical AIS limitations and infrastructure requirements and coordinate them with display requirements. USCG should establish a mechanism to inform all users about system limitations that cannot be corrected readily.

Recommendation 6: USCG should work with stakeholders to develop appropriate training and certification guidelines for AIS users that will lead to effective use and an understanding of system functions and limitations.

Ongoing Research

The development of AIS displays requires consideration of the human interface attributes that affect what information to display, how to present it to the operator, how to integrate other displays or other bridge information systems, and how to give the operator what is most needed to perform critical tasks. A key research area that has received little attention is whether AIS data will be presented to the operator separately or integrated with other equipment and information flows.

Another area for research is how the input of data into AIS during the normal conduct of vessel operations may interfere with mariners' other duties. Additional topics for research include symbology, cost–benefit trade-offs, data input strategies, and multiple tasking.

Recommendation 7: USCG should establish an ongoing research program to investigate information displays and controls appropriate for AIS. The research program should consider AIS use with other navigational and communications technologies. The research program should include

- Human factors aspects of interface design and the subsequent process of determining requirements, setting standards, and evaluating performance;
- Evaluation of multimodal interfaces—for example, tactile and auditory—that could support mariners' needs for attention management.
- Investigation of trade-offs between information requirements and the associated cost for shipboard display of AIS.

Operational Testing

Although USCG and other authorities have conducted operational tests of AIS technology in the United States and abroad, none of the tests has produced clear evaluations of performance measured against specific standards. Few of the tests on displays have involved AIS equipment built to IMO standards.

Recommendation 8: USCG should sponsor continuing operational tests, evaluation, and certification of new display and control technology in consultation with stakeholders and should prepare test and evaluation reports. To conduct tests and evaluations, USCG should develop standards for human performance with display and control technology. Heuristic evaluation should be used, so that several designers can assess how well a design conforms to human factors principles. Usability tests and operational evaluations should be incorporated as complementary approaches to assess how well AIS displays and controls support mariner performance.

The author is Research Associate, TRB Division of Studies and Information Services. Beverly M. Huey, Senior Program Officer, Transportation Research Board, served as Study Director for this project, assisted by Pete Johnson, Consultant.

Committee for Evaluating Shipboard Display of Automatic Identification Systems

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US Army Corps of Engineers ®
US Army Cold Regions Research and Engineering Laboratory

ANTIFREEZE CONCRETE PAVING

Admixtures Facilitate Cold-Weather Construction

CHARLES J. KORHONEN

The author is Research Civil Engineer, U.S. Army Corps of Engineers, Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

Portland cement concrete with commercially available admixtures was placed in Wisconsin and New Hampshire during subfreezing temperatures without heated enclosures, producing savings of 20 to 90 percent in materials and placement costs. The technique could extend the cold-weather construction season by as much as four months in many parts of the United States.

Portland cement concrete generally cannot be placed during subfreezing weather without thermal protection. Recent research by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), however, has demonstrated that commercial admixtures can protect concrete from freezing. The admixtures can extend the concrete construction season into the winter.

Problem

Cold-weather construction practice requires that concrete be delivered warm to the construction site, that the substrate be thawed, and that the concrete be kept warm while curing. At temperatures near 40°F, insulation usually suffices to allow the placement of concrete. When the temperature drops below 40°F, however, heated enclosures, insulation blankets, and other thermal protection become necessary—but are not always practical. As a result, concrete pavements are seldom constructed when air temperatures approach 40°F.

Removing a concrete pavement section in Wisconsin.

Solution

In a pooled-fund project for the Federal Highway Administration, CRREL developed an antifreeze concrete for highway paving at subfreezing temperatures. The project required off-the-shelf admixtures and application at 23°F or lower, with adequate strength, constructability, and economy.

CRREL evaluated combinations of commercially available admixtures to depress the freezing point of water and to accelerate the hydration rate of cement. Previous research showed that no single admixture in recommended amounts could provide enough freeze protection to meet the low-temperature requirement.

Current practices limit the amount of each admixture to concrete. No limits apply, however, to the number of admixtures in a single batch, and concrete with more than one admixture is not uncommon. The literature reports five or more admixtures but does not indicate if the purpose was to prevent the concrete from freezing during application.

CRREL researchers produced candidate formulations by combining several commercial admixtures that met standards, all within the recommended dosages. The formulations were evaluated under controlled laboratory conditions, to identify the admixture combinations that could accelerate curing, ensure workability, provide adequate freezing-point depression, and not harm the freeze–thaw durability.

The laboratory tests indicated an appreciable strength gain for the candidate formulations at 23°F, with no adverse effects on durability. The formulations were then evaluated in field tests.

The demonstrations of the antifreeze concrete technology took place at five locations in Wisconsin and New Hampshire. The concrete was evaluated for

- Batch mixing,
- Transportability,
- Ease of placement,
- Cost and time,
- Compatibility with common practice,
- Finishability, and
- Equipment and labor issues.

In one project in Rhinelander, Wisconsin, in February 2002, a section of pavement 10 feet wide by 22 feet long by 10 inches deep was removed and replaced with antifreeze concrete. The air temperature was 14°F at the start of work, rose to approximately 32°F during placement of the concrete, and then dipped to 10°F in the evening.

Removal of the pavement and replacement with fresh concrete were completed within 3 hours. The freshly placed concrete was covered with a layer of plastic to minimize moisture loss, and an insulation blanket was laid over the plastic to speed up the strength development; the insulation blanket, however, was not necessary for freeze protection.

The pavement section was opened to traffic 48 hours later. Except for the corrosion-inhibiting and accelerating admixtures, the antifreeze concrete contained the same materials in the same proportions as the normal-weather concrete, including the same measures of air-entraining and water-reducing admixtures. Two years after construction, the antifreeze demonstration sections show no signs of distress.

Benefits

Antifreeze concrete made with commercial admixtures allows unprotected placement and normal curing at external temperatures as low as 23°F. Antifreeze admixtures increase the concrete material cost but reduce the placement costs by eliminating the need for heat, shelter, and extra labor.

On the Rhinelander project, the antifreeze technology reduced the cost by nearly 20 percent compared with the cost of using a heated enclosure. The savings on other projects were greater. For example, one New Hampshire project realized a 90 percent reduction in materials and placement costs with antifreeze concrete instead of regular concrete under conventional heated enclosures. After surface preparation, the antifreeze section on this project was placed and finished within a few hours; erecting and dismantling the shelter for an identical control section would have required several days.

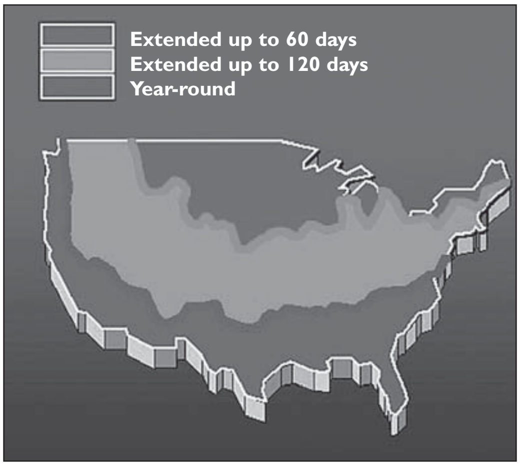


FIGURE 1 Potential extension of construction season with the use of antifreeze concrete.

Use of antifreeze concrete also extends the construction season by 60 to 120 days (Figure 1) and ensures that the concrete can be placed safely on frozen substrates, that it will develop adequate strength despite exposure to low temperatures, and that it will exhibit adequate freeze–thaw durability.

Extending roadway construction into colder seasons, when traffic volume is lower, offers the following benefits:

- Reducing the adverse impact of construction on the public;
- Decreasing the number of work zone accidents; and
- Improving the utilization of construction equipment and labor by extending the seasonal limits of construction work.

For further information contact Charles J. Korhonen, Research Civil Engineer, U.S. Army Corps of Engineers-ERDC, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, New Hampshire 03755-1290, 603-646-4438, e-mail Charles.J.Korhonen@erdc.usace.army.mil.

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

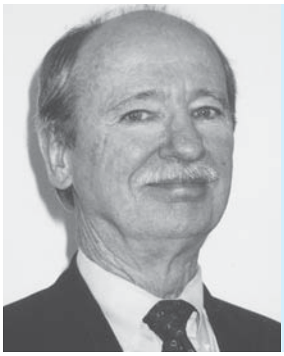
Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail gjayaprakash@nas.edu).

Richard Cheney

Geotechnical Engineer

Geotechnical engineering combines the soil and rock sciences with mechanical skills to solve issues ranging from foundation design to landslide correction. In an engineering career spanning four decades, Richard Cheney has provided expert geotechnical assistance on major highway projects, implemented new technology in earth support systems, and trained thousands of transportation engineers in the application of basic geotechnical concepts.

Cheney worked at the Federal Highway Administration (FHWA) for 21 years and at Parsons Brinckerhoff for 3 years before semi-retiring in 2002. His interest in geotechnical research began in the early 1970s, when he was working for the New York State Department of Transportation (DOT). Cheney coordinated geotechnical work on major projects and developed routine foundation investigations and reports for bridges, canals, earth dams, and buildings. He helped implement pile wave equation analysis and dynamic pile testing as standard practice in New York and represented the DOT in a series of national seminars sponsored by FHWA, to promote the use of the pile wave equation by transportation agencies.



"Geotechnical engineering is a continually evolving specialty that requires research and implementation to improve both the profession and the design and construction of transportation facilities."

After the seminars, Cheney joined FHWA's geotechnical group in Washington, D.C. He evaluated permanent ground-anchor technology, researching and resolving technical concerns about design, system longevity, and development of construction specifications. As a result of his work, FHWA implemented the technology nationwide.

"Coordination with the anchor industry and associated technical groups, such as the Post-Tensioning Institute, was vital," Cheney recalled. "Success was measured by first convincing highway agencies to bid permanent anchor designs against standard structural designs to prove cost effectiveness and then by post-construction monitoring of the anchors to prove longevity."

Early projects verified the design and the construction methodology and produced an average savings of 40 percent compared with standard solutions. By 1989, 2 million square feet of anchored wall was placed under construction at an estimated savings of more than $70 million.

Cheney authored the design and construction manual, *Permanent Ground Anchors*, which served as the primary guide until the late 1990s. When the geotechnical engineering publication, *Ground Anchors and Anchored Systems*, was published later, he served as a technical consultant.

As a senior geotechnical engineer at FHWA, Cheney also provided technical analysis, construction inspection, and resolution of technical issues for major highway projects, such as the Boston Central Artery and the Utah I-15 reconstruction.

Among highway engineers, Cheney is known for his geotechnical training courses for the National Highway Institute. He has presented the four-day workshop on soils and foundations more than 125 times to more than 3,000 engineers. In the workshop, Cheney examines the causes of geotechnical failures, demonstrating the need for routine investigation of foundations. Cheney coauthored the *Soils and Foundations Workshop Manual* with Ronald Chassie in 1982, and he updated the text in 2000 while working for Parsons Brinckerhoff.

In the latter part of his career, Cheney has devoted time to mentoring recent college graduates. He considers the effort vital, because experience plays a large role in solving geotechnical problems.

"Mentors should provide graduates with encouragement, practical experience, and most importantly, the wherewithal to say, 'I do not know the answer,' when faced with the geotechnical unknown," noted Cheney, who is a graduate of Rensselaer Polytechnic Institute. "With time, graduates develop confidence, validate their expertise, and become a resource for both the organization and the geotechnical profession."

Cheney has participated in activities of the American Society of Civil Engineers, World Road Association, and the Post-Tensioning Institute. For TRB, he has served as chair of the Foundations of Bridges and Other Structures Committee and as a member of the Design and Construction Group Council. He is a member of the Transportation Earthworks Committee. Cheney also has assisted in the development of geotechnical engineering priorities and research statements for the proposed new Strategic Highway Research Program.

"Geotechnical engineering is a continually evolving specialty that requires research and implementation to improve both the profession and the design and construction of transportation facilities," he observes.

Cheney received the FHWA Administrator's Superior Achievement Award for exceptional contributions to the state-of-the-art design and construction of geotechnical features of highway projects. In 1998, FHWA honored him with a special award for resolving critical issues so that the construction of mechanically stabilized earth walls could continue on the Utah I-15 project.

Elaine Reiko Murakami

Federal Highway Administration

City planners have relied on personal travel behavior surveys since the late 1940s to record who is traveling, where, and why. For the past 22 years, Elaine Reiko Murakami has worked to improve travel survey methods to generate better quality data for trend analysis and travel forecasting decisions. Through her work with Los Angeles County, the Puget Sound Regional Council, and now with the Federal Highway Administration (FHWA), Murakami has incorporated technology to overcome several pitfalls of self-reported surveys.

Murakami says that telephone surveys—the most common method—can take longer than 20 minutes per person to collect data from a single day of travel because respondents often do not know the addresses of the places they go, such as the grocery store.

"Research on travel behavior is infinitely interesting because humans are not machines," observes Murakami, Community Planner in the Office of Planning at FHWA. "People make choices that a computer model would consider a 'mistake.' This only means that human decision making is very complex. Sometimes people cannot articulate how they make specific decisions of where, when, or how they travel."

"Research on travel behavior is infinitely interesting because humans are not machines. People make choices that a computer model would consider a 'mistake.'"

Murakami notes that reliable, accurate information about route choices is nearly impossible to capture by traditional methods. In 1996 she initiated a research project to incorporate Global Positioning System (GPS) technologies with a handheld computer that, when mounted on a vehicle, would record the time and route of travel. The device weighed nearly 1 kilogram (2.2 pounds) and was used in a personal vehicle and a commercial truck survey. Since then, several GPS-based surveys have been completed by other researchers. Murakami now wants to test lightweight devices that combine GPS with cellular phone data and can be carried by people instead of mounted in vehicles.

Murakami also managed a Small Business Innovative Research project to develop and implement a personal travel behavior survey via the Internet with a geographic information system (GIS) component. The GIS allowed respondents to select a spot on the map to identify a trip destination instead of having to remember the address. The software incorporated an electronic Yellow Pages so that respondents could type in the name of the business, and the location would appear on the map.

Murakami has conducted population forecasting from the decennial census "long form." She used data from the 1980 Census when she worked for Los Angeles County in the Urban Research Division and from the 1990 Census when she joined the Puget Sound Regional Council, the metropolitan planning organization (MPO) in Seattle. At FHWA, Murakami has worked closely with the U.S. Census Bureau to produce the Census Transportation Planning Package (CTPP) 2000 and to conduct research on the implications of replacing the long form with the American Community Survey. Murakami chairs the CTPP 2000 Working Group, which includes the U.S. Census Bureau, the American Association of State Highway and Transportation Officials, the Bureau of Transportation Statistics, the Federal Transit Administration, and FHWA.

Throughout the development of CTPP 2000, Murakami promoted GIS in the data production and data access system. Transportation analysis zones, defined by local governments, were incorporated into the Census Bureau's TIGER files, and improvements were made to employer name and address files for geocoding workplaces. "The last 10 years have seen many advances, with GIS in every MPO, and I hope that I have contributed to that change," Murakami remarks.

She attended the University of California, Santa Cruz, completing a bachelor of arts in environmental planning in 1976, and she earned Master's degrees in planning and in gerontology from the University of Southern California in 1982.

Murakami has served on expert panels for MPO travel surveys, and she has represented the survey research community at TRB. She is a current member and past chair of the Travel Survey Methods Committee, and she has served on National Cooperative Highway Research Program panels on standards for household travel surveys and on transportation planning with data from the American Community Survey.

A member of the Women's Issues in Transportation Committee, Murakami has a special interest in equity and choices in mobility. "Transportation needs are not the same for everyone," she says. "Women live longer and head most single-parent households, but because they are paid lower wages, on average, they have fewer choices for their daily travel."

Murakami tries to interest more women in careers in transportation by reaching out to girls in middle and high schools. She has produced documents showcasing the contributions women have made to transportation and the range of jobs they perform today.

"One of our biggest challenges is finding talented young people to continue in our footsteps," she says. "We need to make sure women are part of the transportation future."

NEWS BRIEFS

Pothole-free street in Rockville, Maryland, overlaid with smooth seal.

"Smooth Seal" Overlay Prevents Potholes

Rockville, Maryland, has almost completely eliminated potholes from its residential and commercial streets as a result of a preventive maintenance strategy put into place in the late 1950s. The approach uses "smooth seal," a thin hot-mix asphalt (HMA) surfacing to keep roads in good condition. Pavements have not required rehabilitation after 30 years of service.

The current specifications are essentially the same as the original. The mix is a fine, dense-graded HMA, containing 65 percent crusher dust and 35 percent natural sand. A medium grade of asphalt, AC-10, maintains the HMA's long-term durability and provides a degree of plasticity for healing cracks.

Smooth seal is not used to overlay structurally deficient streets. In Rockville, many pavements are full-depth asphalt, ranging from 6 inches for secondary pavements, 8 inches for primary, and 10 inches for commercial streets. Thin surfacing in combination with a full depth–deep strength structure provides long-lasting pavement that can be managed throughout its service life at an affordable cost.

The program applies a thin overlay every 10 to 12 years. Hundreds of miles of smooth seal have been placed in Maryland with an average service life of 10 to 15 years.

The typical lift thickness for the mix ranges from 0.5 to 0.75 inches. Residential streets receive about 60 pounds per square yard, and primary and commercial streets receive about 70 pounds per square yard.

Residents appreciate the product because it enhances the appearance of neighborhoods and improves riding quality and skid resistance, with minimal disruption to traffic during construction.

This article is condensed from Potholes Be Gone! *in the May–June 2004 issue of* HMAT *magazine, with permission from National Asphalt Pavement Association.*

Motorists Buckle Up During "Click It or Ticket" Campaign

Seat belt use increased in 40 states and the District of Columbia from May 2002 and to May 2003 during an annual two-week campaign that combines heightened law enforcement with a paid advertising blitz, according to the National Highway Traffic Safety Administration (NHTSA). In a final report released in February, NHTSA stated that belt use by front-seat occupants reached 79 percent in 2003—a four percentage point increase from 2002, considered the equivalent of preventing approximately 1,000 deaths.

The national mobilization effort, which carries the slogan, "Click It or Ticket," is conducted by NHTSA and the National Safety Council in conjunction with highway safety officials and thousands of law enforcement agencies from the 44 participating states, the District of Columbia, and Puerto Rico. From mid-May through Memorial Day Weekend, police officers set up checkpoints, saturation patrols, and routine patrols focusing on zero-tolerance enforcement of seat belt laws. Meanwhile, national and state agencies launched an advertising campaign on television, radio, and in newspapers, targeting males between 18 and 34, a population at risk for motor vehicle crashes and low belt use.

During the 2003 campaign, law enforcement agencies nationwide reported issuing more than 500,000 safety belt citations. That year, state and national agencies spent an unprecedented $25 million dollars on advertising, which was partly funded through the Transportation Equity Act for the 21st Century.

The NHTSA report, *May 2003 Click It or Ticket Safety Belt Mobilization Evaluation*, analyzes observa-

INTERNATIONAL NEWS

Canadian Project Reduces Bus Weights

Transport Canada has completed a research and development (R&D) project for lighter-weight intercity buses that could save millions of dollars, increase energy efficiency, and decrease wear and tear on roads. The Transportation Development Centre, the R&D arm of Transport Canada, worked with bus manufacturer Prévost Car on the two-phase, $1.3-million project to select and develop weight-saving design concepts.

Bus design has changed little in Canada in the past three decades; however, buses have become 25 percent heavier due to increased vehicle size and the installation of climate controls, larger double-glazed windows, and higher horsepower engines, among other improvements.

In a preliminary report, the team found that the curb weight of a 45-foot bus could be reduced up to 20 percent through the use of lightweight composite materials and advanced construction techniques. An analysis of lifecycle costs showed that a 20 percent decrease in bus weight over a 15-year period would result in an estimated savings of more than $255 million.

In Phase 1 of the project, the team considered material substitutions and new designs for the bus structure, seats, windows, luggage racks, and drive axles. The team studied a 100 percent aluminum concept and a variety of hybrid-material, sandwich-panel design concepts using foam core with steel, aluminum, or fiberglass skins. A finite element analysis ensured the structural integrity and appropriate stiffness of each design.

The team estimated that all of the concepts would reduce the weight of the components by 50 percent, or the overall weight of the bus by 9 percent. The new designs would increase the cost of buses by an estimated 12 to 18 percent.

In Phase 2, the team examined a variety of replacement materials and construction techniques for the roof and floor. For example, replacing tional surveys conducted before and after the campaign. Results indicate that respondents became more aware of stepped-up enforcement; however, respondents did not perceive that they were more likely to be ticketed. One survey found that approximately 17 percent of belt nonusers were converted to users in 2003, twice the rate of previous years. The 2004 Click It or Ticket campaign took place May 24 to June 6.

For more information, view full report at http://www.nhtsa.dot.gov/people/injury/airbags/clickit_ticke03/ciot-report04/CIOT%20May%202003/index.htm.

Braking the Rate of Increased Congestion

Peak-hour traffic congestion in almost all large and growing metropolitan regions around the world is almost certain to get worse in the next few decades, no matter what public or private policies are put into place to curb it, according to a recent policy brief from The Brookings Institution, a nonpartisan think tank in Washington, D.C.

In the report, *Traffic: Why It's Getting Worse, What Governments Can Do*, author Anthony Downs blames the inevitable congestion on triple convergence—the flow of traffic in any region's transportation network readjusts to road expansions, public transit improvements, or staggered work hours. Downs explains that if a third lane is added to a highway to combat congestion, the lightened traffic would attract commuters who had used alternative routes or public transit or who had avoided the rush hour, thus filling up the increased highway capacity.

The Brookings Senior Fellow in Economic Studies notes that although it is impossible to eliminate congestion, there are several ways slow the rate of increase:

◆ Offer high-occupancy toll lanes for drivers to avoid congestion for a fee.

◆ Respond more rapidly to traffic-blocking accidents and incidents.

◆ Build more roads in growing areas. Although road building is vulnerable to triple convergence, projected growth of the U.S. populations necessitates more road and lane mileage in peripheral areas.

◆ Install ramp metering to allow vehicles to enter an expressway gradually.

◆ Use intelligent transportation system devices that coordinate signal lights on local streets and that inform drivers about traffic conditions on freeways. Make Global Positioning System equipment available for cars and trucks.

◆ Build new high-occupancy vehicle lanes instead of converting lanes, which reduces road capacity.

◆ Restrict development in peripheral areas with low population density (3,500 persons or fewer per square mile) to stop growth from pushing out farther.

◆ Cluster high-density housing around transit stops to shift a significant percentage of automobile commuters to transit.

◆ Give regional transportation authorities more power and resources so that land and transportation planning can be more focused.

◆ Raise gasoline taxes to discourage automobile travel.

◆ Encourage firms to provide employees who receive free parking with stipends for shifting to carpooling or transit.

For more information, view abstract and full report of Policy Brief #128 at www.brook.edu/comm/policybriefs/pb128.htm.

the stainless steel frame with a fastened aluminum frame saved 1,232 pounds. New floor and roof components were made of metal or glass fiber-skinned sandwich panels glued to aluminum extrusions. This approach saved 730 pounds in the floor and 640 pounds in the roof. Strength, durability, stiffness, acoustic characteristics, and rollover performance were taken into account.

"This work was undertaken to identify and show to bus manufacturers that there are ways and opportunities to reduce bus weight, reduce energy consumption and related greenhouse gas emissions, and comply with the axle weight limits imposed by state or provincial highway regulations," said Claude Guérette, senior development officer for Transportation Development Centre.

The project was partly funded by the Canadian Lightweight Materials Initiative of the federal Program of Energy Research and Development, which supports innovative approaches for applying advanced lightweight material in transportation. Bus part supplier ADS Groupe Composites and engineering firm Martec Ltd. contributed to the project.

Other Transportation Development Centre research projects are under way to examine the feasibility of producing a one-piece lightweight composite bus roof and of using lightweight magnesium in seats. An earlier project examined bus suspension systems and made recommendations that would improve the ride while reducing pavement wear.

Summarized from material by the Transportation Development Centre. For further information about the Intercity Bus Weight Reduction Program, go to http://www.tc.gc.ca/tdc/ projects/road/h/menu.htm.

Weight-saving design concept of a passenger bus in Canada.

COOPERATIVE RESEARCH PROGRAMS NEWS

Evaluating Traffic Safety for Nighttime and Daytime Work Zones

The Intermodal Surface Transportation Efficiency Act established a procedure for documenting crashes in work zones during daytime and nighttime operations. Yet the various crash databases maintained by state departments of transportation (DOTs) and other agencies, such as the Fatal Analysis Reporting System (FARS), fail to yield data that can provide explicit conclusions that compare the danger of nighttime and daytime construction operations.

The data are plagued by uncertainties involving (*a*) the level of detail contained in the data, (*b*) the relationship of crashes to specific work-zone locations, and (*c*) the variation in reporting practices. In the 1999 book, *Improving Night Work Zone Traffic Control*, published by Virginia Transportation Research Council, author Ben Cottrell, Jr., concluded that "although there is a perception that night work zones are less safe than daytime work zones, evidence to substantiate this perception, such as higher accident rates, was not available because of lack of traffic exposure data." Information is needed to assess the characteristics of these crashes in both daytime and nighttime work zones.

Recent research suggests that traffic-related crash rates for nighttime work zones are up to three times higher than those for daytime work zones. If nighttime operations are as dangerous as the data and perceptions suggest, more significant resources should be directed at ensuring worker and driver safety in nighttime work zones. The importance of this issue is magnified as state DOTs increase nighttime work operations to decrease work-zone traffic congestion.

The Texas A&M Research Foundation, College Station, has been awarded a $500,000, 30-month contract [National Cooperative Highway Research Program (NCHRP) 17-30, FY 2004] to determine the crash rates and the nature of traffic-related crashes in nighttime and daytime work zones and to develop work-zone crash reporting recommendations to improve the collection of work-zone crash data.

For further information contact Charles W. Niessner, TRB (telephone 202-334-1431, e-mail cniessner@nas.edu).

Low-Cost Active Warning Systems for Highway–Rail Grade Crossings

Much research has been devoted to improving safety at highway–rail grade crossings, and considerable knowledge exists about driver behavior and crash causation. NCHRP Report 470, *Traffic-Control Devices for Passive Railroad–Highway Grade Crossings*, recommends improvements to traffic control devices at passive crossings, which do not have signals or gates.

Active warning systems that alert drivers to an approaching train are beneficial, but their cost limits the number that can be installed. Some low-cost active warning systems have been developed, but further information on their functionality and performance is needed to facilitate implementation.

Texas Transportation Institute has been awarded a $200,000, 15-month contract (NCHRP Project 03-76B, FY 2004) to identify and assess designs for low-cost, viable active warning systems and components at highway–rail grade crossings.

For further information contact B. Ray Derr, TRB (telephone 202-334-3231, e-mail rderr@nas.edu).

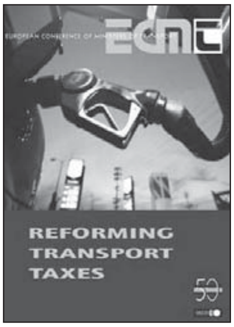
ON TRACK—The TRB Committee for Review of the Federal Railroad Administration Research, Development, and Demonstration Programs held its fifth meeting in April. The project conducts a peer review of safety-related railroad research and development, next generation high-speed rail technology demonstration, and magnetic levitation deployment programs of the Federal Railroad Administration (FRA). Letter reports of the committee's peer-review activities are posted online at www4.nationalacademies.org/trb/onlinepubs nsf/web/reports.

Left: Jo Strang, FRA Deputy Associate Administrator for Railroad Development, listens to a presentation with committee members Gerhard Thelen, Norfolk Southern Corporation; Kenneth Lawson, independent consultant; and Anna Barry, Massachusetts Bay Transportation Authority.

Airport Systems: Planning, Design, and Management
Richard de Neufville and Amedeo Odoni. McGraw-Hill. New York, NY: 2003; 883 pp.; $95 hardcover; 0-071-38477-4.

Coauthors de Neufville and Odoni—recipients of the Federal Aviation Administration's Award for Excellence in Aviation Education—provide a definitive comprehensive resource on all phases of the development of modern airports. The textbook emphasizes how the interactions among the different elements in the air transportation system, including airport competition, organization, and configuration of passenger buildings, contribute to an airport's long-term success. A web page provides updates to the text.

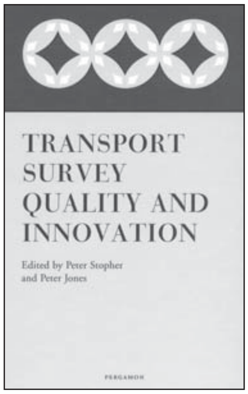
Reforming Transport Taxes
Organisation for Economic Co-operation and Development. Bedfordshire, United Kingdom: 2003; 197 pp.; $46; 9-282-10317-X.



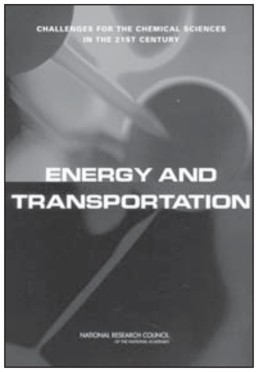
This report examines the economic principles for efficient systems of taxation, providing a framework for international comparisons of transportation taxes and charges. It investigates how motorists, haulers, and users of other transportation services could be affected by price and tax changes likely to result from the reform of transportation charges to maximize efficiency. The report also assesses how differences in national taxation affect haulers competing internationally.

Transport Survey Quality and Innovation
Edited by Peter Jones and Peter Stopher. Elsevier Science Ltd. Amsterdam, Netherlands: 2003; 660 pp.; $120 hardcover; 0-080-44096-7.

This book provides an overview of the latest developments in transportation survey methods from around the world, with an emphasis on survey quality and innovation. Edited by Jones and Stopher, who have served on TRB committees on travel analysis methods, the book includes selected papers from the International Conference on Transport Survey Quality and Innovation, held in South Africa in 2001. The conference covered passenger and freight transportation, with special interest in identifying user needs and exploring accomplishments outside North America and Western Europe.



Energy and Transportation: Challenges for the Chemical Sciences in the 21st Century
National Research Council. Washington, D.C.: 2003; 128 pp.; $29.50 paperback; 0-309-08741-4.



The report summarizes presentations from the Workshop on Energy and Transportation, sponsored in January 2002 by the National Research Council's Board on Chemical Sciences and Technology in the Division on Earth and Life Studies. The sessions highlighted the potential contributions of the chemical sciences in the development of new and improved transportation. The report finds that the keys to improving vehicle efficiency include reducing vehicle mass, changing basic vehicle architecture, and improving power trains. The committee suggests that detailed programs be developed to pursue the goals.

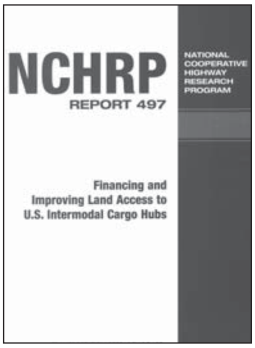
The books described above are not TRB publications. To order, contact the publisher listed.

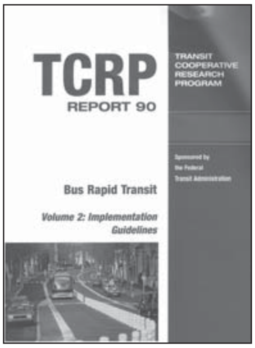
TRB PUBLICATIONS

Financing and Improving Land Access to U.S. Intermodal Cargo Hubs
NCHRP Report 497

Presented are the most effective strategies for financing improvements to cargo hub and intermodal freight facilities. The strategies focus on developing partnerships among government agencies, cargo hub operators and users, and local communities to tap into current and emerging sources of funding. The report also includes analyses of 12 case studies from an inventory of U.S. cargo hub improvement projects. Appendices offer detailed information on each case study, the inventory of projects, and a list of federal and state funding sources.

TRB PUBLICATIONS (*continued*)





2003; 150 pp.; TRB affiliates, $18; nonaffiliates, $24. Subscriber categories: planning and administration (IA); freight transportation (VIII).

Illumination Guidelines for Nighttime Highway Work
NCHRP Report 498
This report provides guidelines for illuminating nighttime highway construction and maintenance, including work zone design and the use of temporary roadway lighting. The guidelines ensure a safe environment for motorists and workers.

2003; 74 pp.; TRB affiliates, $15; nonaffiliates, $20. Subscriber category: materials and construction (IIIB); maintenance (IIIC); safety and human performance (IVB).

Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements
NCHRP Report 499
The effectiveness of subsurface pavement drainage systems for hot-mix asphalt and portland cement concrete pavements is evaluated in this report. Topics include permeable base and associated edgedrains, traditional dense-graded bases with and without edgedrains, and subsurface drainage features retrofitted on existing pavements. The report is based on comprehensive analysis of data available through June 2001 from the Long-Term Pavement Performance experiments.

2003; 52 pp.; TRB affiliates, $14.25; nonaffiliates, $19. Subscriber category: pavement design, management, and performance (IIB).

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan
NCHRP Report 500, Volumes 1–6
The goal of the highway safety guidelines is to reduce the number of annual highway fatalities by 5,000 to 7,000 through the widespread application of low-cost, proven countermeasures that decrease the likelihood of crashes on the nation's highways. The *NCHRP Report 500* series will encompass 22 volumes, each covering one of the plan's key crash scenarios. Each volume includes an introduction, a description of the problem, strategies to address the problem, and a model implementation process.

- *Volume 1: A Guide for Addressing Aggressive-Driving Collisions*; 62 pp.; TRB affiliates, $14.25; nonaffiliates, $19.
- *Volume 2: A Guide for Addressing Collisions Involving Unlicensed Drivers and Drivers with Suspended or Revoked Licenses*; 74 pp.; TRB affiliates, $15; nonaffiliates, $20.
- *Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations*; 63 pp.; TRB affiliates, $14.25; nonaffiliates, $19.
- *Volume 4: A Guide for Addressing Head-On Collisions*; 65 pp.; TRB affiliates, $15.75; nonaffiliates, $21.
- *Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*; 157 pp.; TRB affiliates, $18 nonaffiliates, $24.
- *Volume 6: A Guide for Addressing Run-Off-Road Collisions*; 91 pp.; TRB affiliates, $15.75; nonaffiliates, $21.

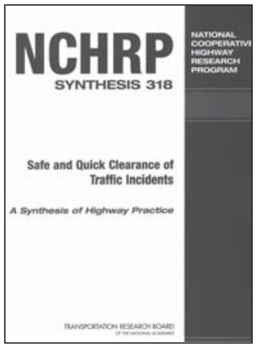
2003; Subscriber category: safety and human performance (IVB).

Integrated Safety Management Process
NCHRP Report 501
This report provides an overall process for coordinating a highway safety program, whereas each volume of *NCHRP Report 500* presents countermeasures for particular highway crash scenarios. The integrated management process consists of steps—from gathering crash data to developing integrated action plans—and includes methods for identifying problems, optimizing resources, and measuring performance. The process enables agencies that are responsible for highway safety within a jurisdiction to integrate and coordinate safety-related implementation actions. A diskette containing software and spreadsheets is included.

2003; 147 pp. plus diskette; TRB affiliates, $21.75; nonaffiliates, $29. Subscriber category: safety and human performance (IVB).

Bus Rapid Transit, Volume 2: Implementation Guidelines
TCRP Report 90, Volume 2
Volume 2 addresses the main components of bus rapid transit, including planning considerations, key issues, the system development process, desirable conditions, and general planning principles. It also provides an overview of system types and elements, including stations, vehicles, services, fare collection, running ways, and ITS applications.

2003; 251 pp.; TRB affiliates, $20.25; nonaffiliates, $27. Subscriber categories: public transit (VI).



Traveler Response to Transportation System Changes Handbook
TCRP Report 95

The *TCRP Report 95* series comprehensively documents various transportation system changes, policy actions, and alternative land-use and site-development design approaches. This third edition of *Traveler Response to Transportation System Changes* covers 18 topic areas—including 9 new areas—each of which will be published separately as a chapter.

◆ *Chapter 11: Transit Information and Promotion*

Chapter 11 focuses on a subset of transit marketing—transit information and promotion—and examines traveler response to mass market information, mass market promotions, targeted information, targeted promotions, customer information services, and real-time transit information dissemination.

71 pp.; TRB affiliates, $15; nonaffiliates, $20.

◆ *Chapter 15: Land Use and Site Design*

Chapter 15 focuses on the relationships between land use–site design and travel behavior.

133 pp.; TRB affiliates, $15; nonaffiliates, $20.

◆ *Chapter 18: Parking Management and Supply*

Chapter 18 focuses on how travelers respond to differences in the supply and availability of vehicle parking that may occur, for example, from shifts in land-use patterns, changes in regulatory policy, or attempts to "manage" the supply of parking.

86 pp.; TRB affiliates, $15; nonaffiliates, $20.

2003; Subscriber categories: planning and administration (IA); highway operations, capacity, and traffic control (IVA); public transit (VI).

Safe and Quick Clearance of Traffic Incidents
NCHRP Synthesis 318

Quick clearance is the practice of rapidly and safely removing temporary obstructions from a roadway. This synthesis profiles the laws, policies, and procedures for facilitating the safe and efficient clearance of traffic incidents, primarily those that block travel lanes and that are attended to by the vehicle's operator. The study reports on traffic incident clearance and investigation activities that quickly mitigate incidents of varying severity, from a single disabled vehicle or minor crash to a serious crash or nonhazardous cargo spill.

2003; 143 pp.; TRB affiliates, $14.25; nonaffiliates, $19. Subscriber categories: highway operations, capacity, and traffic control (IVA); *safety and human performance* (IVB).

Bridge Deck Joint Performance
NCHRP Synthesis 319

Bridge deck expansion joints allow for longitudinal movement and a small amount of rotation in every bridge. These motions are initiated by live loads, thermal changes, and the physical properties of the bridge. Damage to deck joints on U.S. bridges costs millions of dollars each year. This includes damage to both the joint and the portion of the bridge beneath the joint that is exposed to debris and contaminants. This synthesis provides state-of-the-practice findings about commonly used joint systems, summarizes performance data for each system type, and includes examples of selection criteria and design guidelines. The report includes lessons learned for maximizing the service life of joint systems and methods to determine if the joints are watertight.

2003; 46 pp.; TRB affiliates, $11.25; nonaffiliates, $15. Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); *materials and construction* (IIIB); *maintenance* (IIIC).

Human Performance, Simulation, User Information Systems, and Older Person Safety and Mobility
Transportation Research Record 1843

Research presents characteristics of cell phone–related motor vehicle crashes in North Carolina, the sensory cause of railroad grade-crossing collisions, the effectiveness of ground-mounted diagrammatic advance guide signs for freeway entrance ramps, and consequences of driving reduction or cessation for older adults.

2003; 112 pp.; TRB affiliates, $33; nonaffiliates, $44. Subscriber category: safety and human performance (IVB).

Design of Structures 2003
Transportation Research Record 1845

This eight-part volume provides design concepts for general structures, steel bridges, concrete bridges, tunnels and underground structures, and culverts and hydraulic structures, along with research into the dynamics and field testing of bridges, structural fiber-reinforced plastics, and seismic design of bridges. Papers present research

on the fundamental flaws in the appearance of bridges, the effects of distortion on the strength of curved I-shaped bridge girders, the structural performance of storm water detention system with bundled high-density polyethylene pipes, and a seismic analysis and displacement-based evaluation of the Brooklyn–Queens Expressway, New York.

2003; 225 pp.; TRB affiliates, $40.50; nonaffiliates, $54. Subscriber category: bridges, other structures, and hydraulics and hydrology (IIC).

Transportation in Developing Countries
Transportation Research Record 1846
This volume presents international research, including a development impact study of the Beijing–Tongjiang Expressway, a safety and efficiency strategy for urban road transport in Asia, strategies to promote the safety of vulnerable road users, and traffic safety diagnostics and application of countermeasures for rural roads in Burkina Faso.

2003; 61 pp.; TRB affiliates, $28.50; nonaffiliates, $38. Subscriber category: safety and human performance (IVB).

Operational Effects of Geometrics 2003
Transportation Research Record 1847
Topics include the safety effects of converting intersections to roundabouts, the use of M/G2/1 queuing to determine storage lengths of left-turn lanes at unsignalized intersections, the comparison of operations of single-point and tight urban diamond interchanges, and the optimal location of u-turn median openings on roadways.

2003; 65 pp.; TRB affiliates, $28.50; nonaffiliates, $38. Subscriber category: highway operations, capacity, and traffic control (IVA).

Transportation Management and Public Policy 2003
Transportation Research Record 1848
A methodological framework for assessing transportation policies is applied to the Athens 2004 Olympic Games; results are reported on the implementation of an engineer-in-residence concept in the Department of Civil Engineering and Mechanics at the University of Wisconsin; and educational needs in spatial data, information science, and geomatics are addressed in the context of the civil engineering undergraduate curriculum.

2003; 136 pp.; TRB affiliates, $34.50; nonaffiliates, $46. Subscriber category: planning and administration (IA).

Air Transportation Challenges: Airspace, Airports, and Access
Transportation Research Record 1850
The implementation of a small aircraft transportation system in Nebraska, the privatization of part of United Kingdom's airspace, critical assessment of airport demand management strategies in Europe and the United States, and intermodal trip planning decisions in interurban networks are examined.

2003; 82 pp.; TRB affiliates, $30; nonaffiliates, $40. Subscriber category: aviation (V).

Highway and Facility Design 2003
Transportation Research Record 1851
This five-part volume addresses geometric design; hydrology, hydraulics, and water quality; roadside safety features; landscape and environment; and utilities. Research findings include the effects of load distribution, cargo type, and road design characteristics on heavy truck dynamic rollover; design and testing of tie-down systems for temporary barriers; and the development of an energy-absorbing composite utility pole.

2003; 157 pp.; TRB affiliates, $36; nonaffiliates, $48. Subscriber category: highway and facility design (IIA).

Traffic Flow Theory and Highway Capacity 2003
Transportation Research Record 1852
The 32-paper volume includes a comparison of *Highway Manual 2000* and Dutch guidelines, probabilistic traffic flow breakdown in stochastic car-following models, numerical analysis of freeway traffic flow dynamics for multiclass drivers, and a framework for investigation of level-of-service criteria and thresholds on rural freeways.

2003; 270 pp.; TRB affiliates, $42; nonaffiliates, $56. Subscriber category: highway operations, capacity, and traffic control (IVA).

Pavement Management and Rigid and Flexible Pavement Design 2003
Transportation Research Record 1853
Pavement management, rigid pavement design, and flexible pavement design are covered in this three-part volume. Papers assess the impact of bus traffic on pavement maintenance costs in Los Angeles; examine the application, performance, and lessons learned from a 10-year program of dowel-bar retrofit; and compare as-constructed and as-designed flexible pavement layer thicknesses, among other topics.

2003; 176 pp.; TRB affiliates, $37.50; nonaffiliates, $50. Subscriber category: pavement design, management, and performance (IIB).

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