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52 pages | | PAPERBACK
ISBN 978-0-309-42872-9 | DOI 10.17226/23296

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TR News: September-October 2005
Transportation Noise: Measures and Countermeasures

TR NEWS

NUMBER 240 SEPTEMBER–OCTOBER 2005

CONTROLLING TRANSPORTATION NOISE

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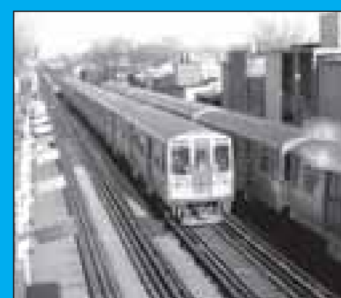

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COVER: Transportation noise is inevitable and inescapable—and close to home. What can be done to control it?
(*Photo: Corbis*)

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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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TR News (ISSN 0738-6826) is issued bimonthly by the Transportation Research Board, National Research Council, 500 Fifth Street, NW, Washington, DC 20001. Internet address: www.TRB.org.

Editorial Correspondence: By mail to the Publications Office, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, by telephone 202-334-2972, by fax 202-334-3495, or by e-mail jawan@nas.edu.

Subscriptions: North America: 1 year $55; single issue $9.50. Overseas: 1 year $75; single issue $13.50. Inquiries or communications concerning new subscriptions, subscription problems, or single-copy sales should be addressed to the Business Office at the address below, or telephone 202-334-3216, fax 202-334-2519. Periodicals postage paid at Washington, D.C.

Postmaster: Send changes of address to *TR News*, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001.

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Printed in the United States of America.

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ALSO IN THIS ISSUE:

COMING NEXT ISSUE

Three participants in the historic AASHO Road Test evaluate the legacy for bridge research; a transportation engineer offers insights into the federal legislative process from experience as a staffer on Capitol Hill; how an outreach program is connecting precollege students to the world of transportation professionals; a statistical engineer presents a personal view of the development of highway quality assurance; and a look at trends in federal transportation research funding are featured in the November–December *TR News*.

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INTRODUCTION

CONTROLLING TRANSPORTATION-RELATED NOISE AND VIBRATION

Examining the Sources, Preventing Impacts

More than 30 years ago, the National Environmental Policy Act set the tone for the nation's commitment to environmental protection and stewardship. Federal agencies were charged with establishing regulations, criteria, and standards for a range of environment-related issues, functions, and disciplines. In the early to mid-1970s, additional legislation and regulations focused on specific environmental issues. The articles on the following pages examine developments in the area of environmental noise and vibration from transportation sources.

Noise may have the most pervasive environmental impact on people. According to surveys in the early 1970s, more than half of the people who classified their community as noisy cited motor vehicles as the dominant source of noise.[1] As retail, manufacturing, and personal activities in the United States have moved to a 24-hours-a-day, 7-days-a-week schedule, a nonstop, multimodal transportation network has developed.

Expanding the infrastructure by widening roads or building new roads, by adding runways and increasing operations at airports, or by offering high-speed rail for long-distance commuters has consequences—the noise levels increase, as do the areas or zones of impact. Noise and vibration can be minor irritants at low levels for short periods, but at higher decibel levels and over longer periods, noise and vibration can have adverse health effects, can interfere with and detract from normal activities, and ultimately can degrade the quality of life.

Recognizing the potential detrimental effects of noise, transportation professionals are committing resources to

- Understand the basic physical properties of noise generation and propagation;
- Improve the accuracy and reliability of noise measurements;
- Develop and refine techniques to forecast accurately and effectively the levels of noise from transportation sources; and
- Identify effective noise mitigation measures and forecast the benefits.

[1] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, Report No.550/9-74-004, Office of Noise Abatement and Control, U.S. Environmental Protection Agency, March 1974.

Transportation professionals have embraced a three-pronged approach to noise control, addressing (*a*) control of the source, (*b*) land use planning and control, and (*c*) mitigation at the receiver, or path control. The approach has become more important in a multimodal world.

Professionals in all the transportation modes are working on techniques to reduce noise and vibration at the source and at the receiver. Design innovations in pavements, aircraft engines, and propulsion systems for subways and rail, for example, have reduced the magnitude of noise at the source. These advances, however, are not enough. The basic problem is the exposure of people, wildlife, and manufacturing activities to noise and vibration. Professionals therefore endeavor to regulate land uses adjacent to noise sources, to adjust neighborhood and building designs, and to develop criteria and standards to reduce exposure.

Improved design tools and techniques are providing more effective barriers to prevent unavoidable noise and vibration from reaching the receiver. The world would be noisier today without these concerted efforts to minimize noise emissions at the source and to address noise impacts.

Members and friends of the TRB Transportation-Related Noise and Vibration Committee contributed the articles in this issue, covering a range of topics and research, as well as national, state, and local activities to mitigate and avoid the effects of noise and vibration. The committee—including three modal subcommittees: Aircraft, Highway, and Guided Rail and Transit—functions as a clearinghouse and meeting place for the exchange of information and research results; performs peer review of papers for the TRB Annual Meeting and for publication in TRB's journal; and identifies and promotes research needs in noise and vibration. The committee welcomes comments on this issue of *TR News*, as well as participation in committee activities.

—Kenneth D. Polcak
Maryland State Highway Administration
Chair, TRB Transportation-Related Noise and Vibration Committee

EDITOR'S NOTE: Appreciation is expressed to Kimberly Fisher and Frederick Hejl, Senior Program Officers in the TRB Technical Activities Division, for their efforts in developing this issue of *TR News*.

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TR News: September-October 2005
Transportation Noise: Measures and Countermeasures

ADDRESSING THE NOISE FROM U.S. TRANSPORTATION SYSTEMS

Measures and Countermeasures

NICHOLAS P. MILLER

The author is Senior Vice President, Harris Miller Miller & Hanson, Burlington, Massachusetts.

Transportation systems, vital to the U.S. economy, are the predominant source of sounds outdoors. How detrimental these sounds are to human health and well-being is a subject of continuing debate. When loud enough and frequent enough, however, the sounds diminish the quality of life (see box, page 6).

Transportation Sound Levels

Estimates of the maximum sound levels produced by common transportation sources are shown in Table 1; waterway sources are not included. Sound levels should be associated with a location on the ground or with a distance from the source; the levels in Table 1 are associated with specific distances and operating conditions.

The aircraft sound levels are for distances of 1,000 feet, and the ground transportation sources are for 50 feet—the distances at which the source sound levels can be measured reliably. The derivation of sound levels at other distances requires information about factors that affect the propagation of sound—such as the terrain, the location of buildings or other shield-

Photo: Larry Levine, WMATA

Metrorail and automobile traffic on Interstate 66 in suburban Washington, D.C., pass through residential neighborhoods protected from the noise by barrier walls and landscaping.

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ing structures, the meteorological conditions, the aircraft engine mounting, the aircraft elevation, and the direction of flight in relation to the listener. The maximum levels at a distance of 50 feet would be at least 25 decibels (dB) lower if heard at 1,000 feet.

The levels for the surface transportation sources are from federal agency models. The aircraft levels derive from the Federal Aviation Administration's (FAA's) aircraft noise model data and from field measurements. The sound levels should be considered typical or average; actual levels will vary above and below those indicated in the table.

No Escape

Stand outside almost anywhere in the continental United States, and within a short time—probably less than 1 hour—the sound of a truck, automobile, airplane, or train will be audible. The percentage of land in each county in which the various transportation sources are likely to be heard during the daytime can be estimated from standard transportation sound levels, the routes followed by each mode, and estimates of the background sound levels throughout the continental United States.

Figures 1, 2, and 3 show the percentages of land in each county in which the sounds of roadway traffic, rail traffic, and high-altitude jets may be heard (*1*).

The roadway results represent the network of limited access, primary, and secondary roads; local roads are not included. The rail results are for freight lines only, and the aircraft results are for high-altitude intercity jet traffic only—general aviation operations or departures and arrivals in the vicinity of airports are not included. The road and jet results, therefore, are likely to be underestimates, particularly for densely populated areas and for the vicinity of major airports.

Aircraft Noise

Aircraft noise is an issue for people who live near airports. Noise is the reason most often cited for public resistance to increases in runway capacity or to alterations in the use of airspace.

Aircraft-produced sound can reach levels that interfere with speech outdoors in communities some distance from an airport. For example, a modern commercial jet can produce sound levels of 70 dB(A)[1] to 80 dB(A) up to 3 miles from a runway, loud enough to interfere with speech outdoors for about 20 to 35 seconds. A moderately busy commercial airport with 200 to 300 daily departures could interfere with speech 10 to 20 times per hour.

[1] dB(A) = A-weighted decibels. See box, page 6.

TABLE 1 Approximate Maximum Sound Levels for Transportation Sources

Source Type	Estimated Speed/ Operating Condition	Approximate Maximum A-Weighted Sound Level, dB(A)	Distance, feet
Aircraft			
Commercial jet	Takeoff	85	1,000
Commercial jet	High Altitude Cruise	85	1,000
Corporate jet	Takeoff	85	1,000
Propeller aircraft	Takeoff	70–80	1,000
Helicopter	Cruise	70	1,000
Roadway Vehicles			
Heavy truck	50 mph	83	50
Medium truck	50 mph	79	50
Automobile	50 mph	72	50
Rail Vehicles			
Diesel locomotive	50 mph	88	50
Rail cars	50 mph	80	50
Locomotive horns	-	96–110	50

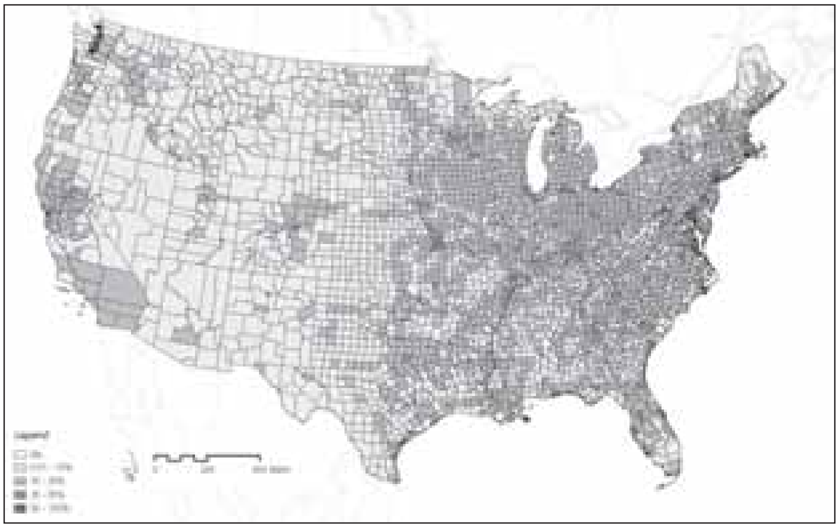
dB(A) = A-weighted decibels, a summation of sound levels across frequencies.

Aircraft Sound Metric

FAA has identified a day–night average sound level (DNL) of 65 dB from aircraft operations as the limit of acceptability for residential housing (see Figure *A*, page 6). Federal funding is available to assist with sound insulation and property acquisition in areas with noise above the acceptable level. The federal government, however, does not set land use policies; local authorities determine the relationship between land use and sound levels.

DNL is a measure of total sound energy in 24 hours and therefore may include many combinations of aircraft sound levels and events. Three

FIGURE 1 Percentages of county areas in which the sounds of road traffic are noticeable during the day.



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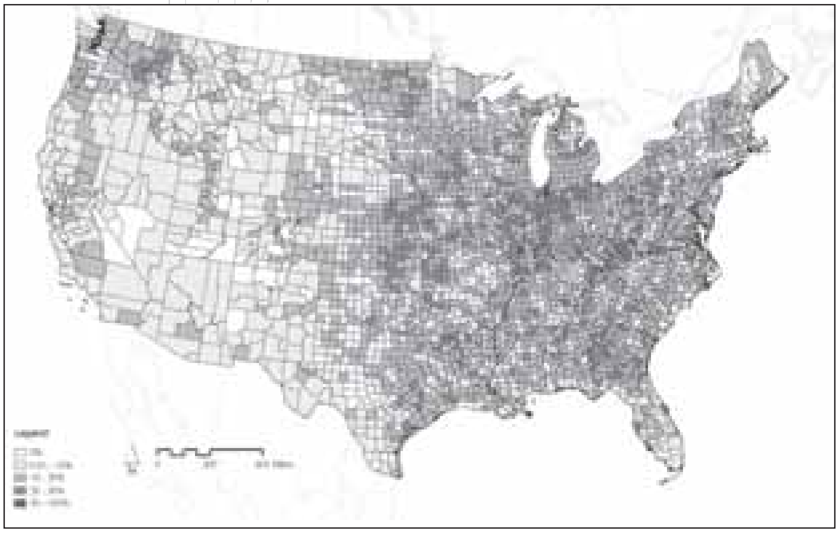

FIGURE 2 Percentages of county areas in which the sounds of rail traffic are noticeable during the day.

example combinations of sound levels and operations that would produce a DNL of approximately 65 dB—assuming that all operations occur between 7 a.m. and 10 p.m.—are shown in Table 2 (page 9). Levels that exceed 60 dB(A) would begin to interfere with normal conversations outdoors.

Aircraft Noise Issues

Because commercial jet aircraft departures and arrivals are the primary sources of noise exposure in the vicinity of airports, any proposal that may increase the number of flights or alter the neighborhoods over which the aircraft fly is likely to arouse public concern. Lengthening runways, building runways, or adding gates—any plan that could be perceived to increase the sound exposure from aircraft—can generate public resistance.

Around airports with no scheduled commercial operations, loud jet or loud propeller operations are a

Introduction to Sound Metrics and Criteria

Sound is quantified either as a total accumulation of sound energy for a period of time or as a measure of a single event. Almost all environmental sound is measured in A-weighted decibels [dB(A) or dBA]. A-weighting is a summation of the sound levels across frequencies; this summation de-emphasizes the levels at different frequencies and corresponds to the way people hear.

The total accumulation metrics are called equivalent levels and represent the sound levels for either 1 hour, symbolized as $L_{Aeq,H}$, Leq(H), or L_{eq}—if the time period is defined—or a 24-hour period,

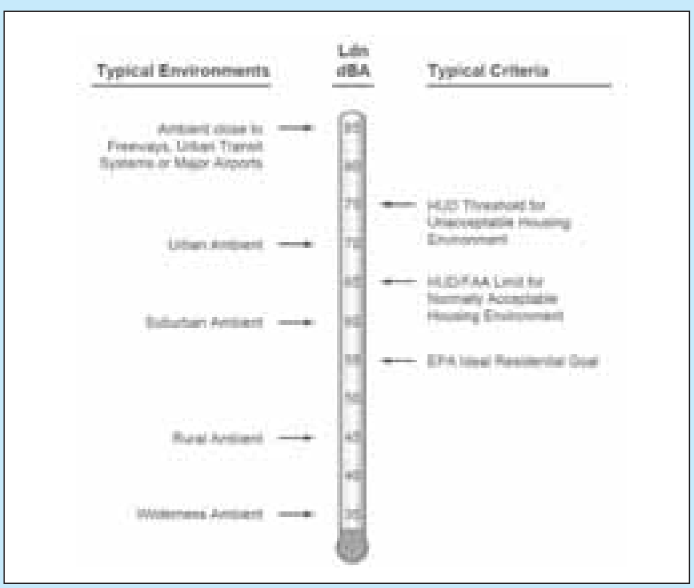

FIGURE A Typical values of DNL.

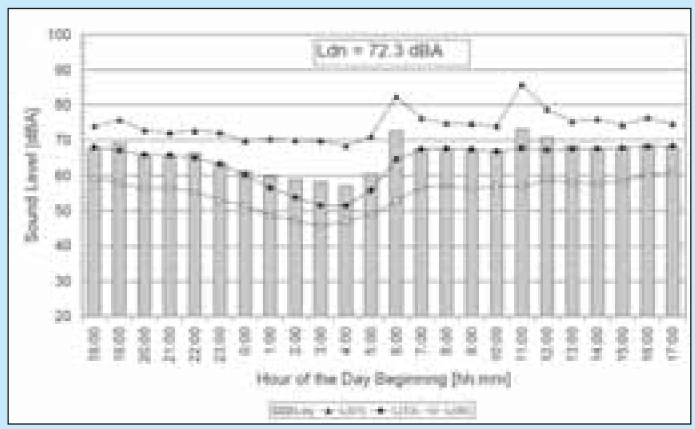

FIGURE B A 24-hour measurement.

called the day-night average sound level (DNL or L_{dn}). DNL includes a weighting or penalty of 10 dB for sound that occurs between 10 p.m. and 7 a.m.

Single events are quantified as an accumulation of sound energy over the duration of the event, termed the sound exposure level (SEL); or as a maximum level, L_{max}; or as the length of time that the sound was above a specified threshold, known as time above (TA).

According to the U.S. Environmental Protection Agency (EPA), cumulative sound exposure below 55 dB DNL poses minimal risk of adverse effects on human health, as well as minimal annoyance. Figure *A* shows typical values of DNL for various locations and identifies the levels established by EPA, the Department of Housing and Urban Development, and the Federal Aviation Administration in making decisions about funding assistance.

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source of noise exposure and, if frequent or at night, a likely cause of complaints. A few loud corporate jets a week, for example, can raise public concern, regardless of DNL values. In areas with no loud jet operations, the sound of propeller aircraft flying over quiet neighborhoods, if frequent enough—particularly on weekends—may raise concern.

Helicopters are not usually louder than other aircraft (see Table 1) but can be identified easily by sound, especially when "blade slap" occurs, and can cause complaints. Helicopters also travel slower than fixed-wing aircraft and can be heard for a longer time.

Other aviation-related sources of sound include engine testing for maintenance or before a flight; auxiliary power units that provide electricity while the aircraft is at a gate; taxiing aircraft; and the low-frequency rumble from jets at takeoff. This last source is difficult to assess and control because the A-weighted sound level does not represent low-frequency

PHOTO: ERIKA LLOYD

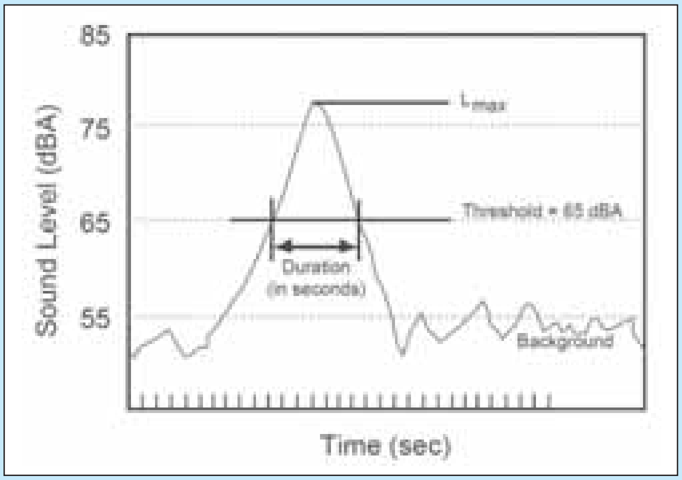

FIGURE C Single-event time history.

The federal agencies responsible for managing transportation noise have established criteria, standards, or guidelines to identify when an impact occurs and when an increase in sound is substantial. If a study indicates that a federally funded project would produce an impact or a substantial increase in sound level, specific actions are required, including a detailed analysis and an examination of ways to reduce the noise. Under certain conditions, federal funds are available for noise reduction. The reductions must meet minimum goals, and the methods or actions must be technically and economically feasible.

Hourly equivalent levels contribute to the value of DNL for the 24-hour period; Figure *B* shows the measured levels at one site, indicating little variation from hour to hour, except in the middle of the night. L(01), L(33), and L(90) are the levels exceeded 1 percent of the hour, 33 percent of the hour, and 90 percent of the hour, respectively.

Figure *C* charts the sound level of a single event, showing the maximum level and the TA. Figure *D* compares several typical maximum sound levels.

As the summation of all the sound energy in a single event, the SEL is generally 5 to 10 dB higher than the maximum. The SEL reflects the duration of a sound and provides a more complete estimate of the disruptive or annoying quality of an event.

FIGURE D Typical maximum sound levels.

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Propeller Buzz, Jet Roar, and Airframe Noise

Causes and Controls

JOSEPH CZECH

Everyone is familiar with aircraft noise—the deep rumble of a jet taking off or the whistling whoosh of an airplane approaching the runway. The causes of these noises, however, are less familiar.

Aircraft noise has two main sources: the propeller-driven or jet engines and the airframe. Engine noise is wasted or lost energy. Only a minute portion of the engine's power radiates as noise but is sufficient to create problems for the neighborhoods around airports.

The noise generated by a propeller is a buzzing, caused by the propellers slicing through the air. The pitch or frequency of the noise is directly related to the speed of the propeller. If the propeller spins faster, the pitch goes up; if slower, the pitch goes down.

Reducing propeller noise is almost impossible—producing the thrust for flight is what causes the noise. Advanced aerodynamic modeling techniques have developed lower-noise propeller designs, but the decrease is limited.

In contrast, jet engines have two major noise-producing sources. The first is called compressor whine, the high-pitched whistling from the front of the engine. The spinning machinery inside the engine is the cause, most noticeably when an aircraft is approaching a runway. Sound-absorbing liners along the inlet of the jet engine can reduce compressor whine.

Photos: Wyle Laboratories

The other source of noise from a jet engine is the hot, high-speed jet of air that streams out the back. This is commonly called jet noise—the deep rumbling when a jet aircraft takes off. The mixing of the hot, high-speed jet of air from the engine with the cold, slow air moving around the engine causes jet noise. The faster and hotter the jet of air exiting the engine, the stronger the mixing and the louder the rumbling behind the engine.

Lowered landing gear contributes to airframe noise in flight.

A high-bypass engine design reduces jet noise by creating a second, cooler, and slower flow of air around the hot central core jet. The second stream is still much faster than the air around the engine but acts as a sheath effectively reducing the speed of the air exiting the engine. The second stream holds down the magnitude of the mixing and the resultant noise. The design also improves fuel efficiency, an added bonus.

As the engine noise becomes quieter, the noise generated by the airframe becomes more predominant. Like jet noise, airframe noise is caused by the mixing of air, but from aerodynamic inefficiencies.

For example, the lowered landing gear on an aircraft causes noise as the air forcibly flows around the gear and mixes with the relatively undisturbed air. Similarly, the flaps that are lowered for landings and takeoffs cause mixing and create more noise. Even structural details like recessed windows can create noise. Airframe designers try to eliminate as many of these potential noise sources as possible, to hold down the total noise from the aircraft.

A variety of advances have reduced aircraft noise, and in the past 25 years the number of people with significant exposure to aircraft noise has decreased from approximately 7.5 million to 0.5 million. Nevertheless, reducing aircraft noise emissions remains a necessity.

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sounds—low-frequency sound propagates farther, with less attenuation, than high-frequency sound; and low-frequency sound penetrates into houses more readily than does high-frequency sound.[2]

Controlling Aircraft Noise

FAA has an ongoing program to reduce the number of noise-sensitive areas exposed to high levels of aircraft noise (*2*). Airports can conduct a federally funded Part 150 Study to identify actions to reduce aircraft noise in sensitive areas—a federally funded project is not necessary to initiate a study.

Several methods can limit residential exposure to aircraft noise, including the acquisition by an airport of properties in the highest noise areas—for example, with a DNL greater than 70 or 75 dB from aircraft; houses, schools, and churches can be insulated for sound; preferred runways can be used, if wind conditions permit; flight corridors also can be altered; and cockpit procedures can be developed for the best use of thrust, speed, and climb, to limit departure and arrival noise.

The success of any of these methods, however, depends on trust and good communication with the communities and with the aircraft operators. Residents often do not understand how an airport operates, how airspace is managed, and the degree of flexibility that airports, air traffic controllers, and pilots have in managing flight operations. Aviation professionals are realizing the importance of developing clear, forthright communication and dialog with residents.

The distribution of responsibilities complicates attempts to limit the conflicts between noise-sensitive land use and aviation noise. FAA controls the airspace, the pilot is responsible for flying the plane, local jurisdictions determine land use, and the airport meets aviation needs and provides convenient passenger service. These stakeholders must work together to minimize the noise exposure for noise-sensitive lands.

Noise from Roadways

At high volumes and speeds, roadway traffic can produce an almost constant sound level, punctuated by increases from noisy vehicles or loud trucks—although noticeable, the increases are not dramatic and are not likely to exceed the general level by more than 5 to 10 dB. In contrast, the sound of sparse nighttime traffic primarily of heavy trucks is a series of single events.

Noise from roadway traffic became a significant issue in the early 1970s, when the Interstate system was extending through cities, towns, and residential areas. In response to legislation requiring documentation of the environmental effects of federally funded projects, the Federal Highway Administration (FHWA) developed methods to measure, predict, and control highway traffic noise (*3, 4*).

[2] A-weighting is a summation of the sound levels across frequencies. See sidebar, page 6.

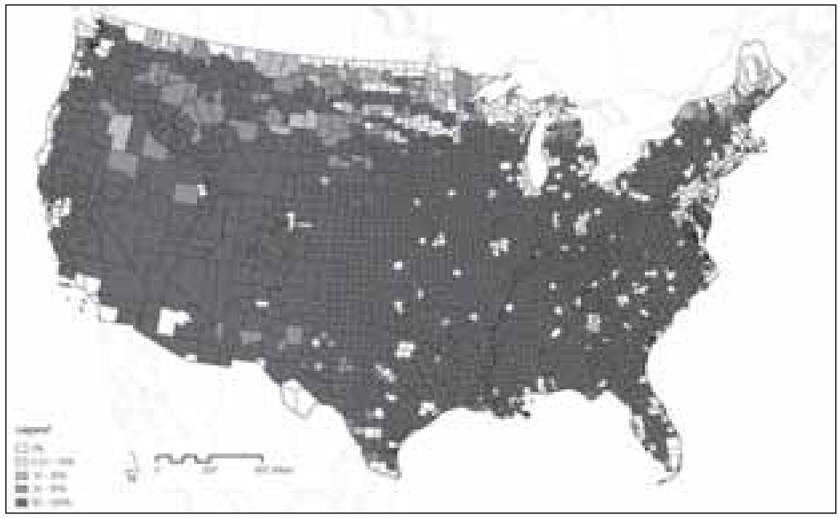

FIGURE 3 Percentages of county areas in which the sounds of jet traffic are noticeable during the day.

TABLE 2 Aircraft Sound Levels and Number of Operations to Produce DNL of 65 dB

Maximum Sound Level, dB(A)	Required Number of Operations in 24 hours	Approximate Time Above 60 dB(A) for Each Operation	Approximate Total Time Above 60 dB(A) in 24 hours
95	10	50 seconds	8 minutes
85	100	35 seconds	1 hour
75	1,000	20 seconds	6 hours

Roadway Traffic Sound Metric

FHWA has determined that traffic noise impacts occur when predicted levels of traffic noise approach or exceed the Noise Abatement Criteria (*5*). Impacts also can occur when predicted noise levels substantially exceed existing sound levels.

Roadway traffic noise is evaluated with an hourly A-weighted equivalent sound level, Leq(h). When the predicted traffic noise for the loudest hour in a residential location regularly approaches or exceeds 67 dB(A) Leq(h), noise abatement must be considered.

To gain funding, an abatement measure must reduce noise substantially and affordably. FHWA permits states to determine the approach-or-exceed level, the amount of reduction a measure would provide, and whether the costs are reasonable.

Table 3 provides 1-hour equivalent sound levels measured at 150 feet from the center of a roadway for

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PARTNER

Partnership for Air Transportation Noise and Emissions Reduction

ROBERT J. BERNHARD

The Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) was established in September 2003 to serve as the Center of Excellence for Aircraft Noise and Aviation Emissions Mitigation. PARTNER fosters breakthrough technical, operational, and workforce capabilities for quieter and cleaner aircraft and works to enhance understanding of aerospace environmental issues. The Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and Transport Canada cosponsor the center.

PHOTO: LEE ADCOCK

Nine universities have developed an integrated plan for research, dissemination of research results, education, and center operations and financing, with Massachusetts Institute of Technology as the lead: Boise State University, Florida International University, Pennsylvania State University, Purdue University, Stanford University, University of Central Florida, University of Missouri–Rolla, and York University. PARTNER's research agenda was developed in collaboration with 32 industrial, government, community, and professional organizations involved in aviation.[1]

PARTNER research will provide critical information to government decision makers and industry executives for addressing the environmental impacts that challenge the growth of civil aerospace. The center also will train the next-generation workforce to meet the continuing challenges of aviation environmental issues.

Following are some of the projects under way:

- Low-Frequency Noise Study, involving experimentation and analysis; findings could lead to regulatory action and the development of technology to mitigate the impacts of low-frequency noise.
- Measurements, Metrics, and Health Effects of Noise, developing metrics to evaluate the impact of airport noise on a community, including noise annoyance, physiological responses, cognitive performance, and sleep quality.
- Continuous Descent Approach, devising procedures to decrease aircraft noise and reduce emissions and fuel burn.
- Land Use and Airport Controls, studying the effects of aviation noise and how to apply the information to improve land use in and around airports.
- Supersonic Transport, investigating the acceptability of shaped sonic booms from a new class of supersonic business aircraft.
- NoiseQuest, assembling a website resource of educational information about aviation noise for airports and communities.
- Measurements, Metrics, and Health Effects of Emissions, characterizing aircraft and airport emissions to determine the health effects.
- Aircraft and Climate, modeling the effects of aircraft on the atmosphere to understand how aviation may contribute to climate change.
- Valuations and Trade-Offs of Policy Options, developing tools and metrics to quantify the environmental impacts of aviation and to evaluate interactions between technology, operations, policy, and the environment.
- Report to the U.S. Congress: Aviation and the Environment, outlining a national vision statement, a framework for goals, and recommended actions.
- Lateral Alignment in Complex Systems, working interactively through NASA's Joint Planning and Development Office with stakeholders in aviation and the environment to forge policies and processes for enhanced communication and collective action.
- Environmental Design Space, developing tools to evaluate the trade-offs at the aircraft system level between noise, emissions, and performance, to support policy decision making.

The author is Professor of Mechanical Engineering, Purdue University, West Lafayette, Indiana.

[1] http://partner.aero.

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different traffic mixes and speeds. During any of the scenarios, the sound would interfere with speech almost continuously. A 13-foot-high noise barrier 25 feet from the edge of the roadway would reduce levels by 8 to 9 dB—a noticeable difference that would improve the audibility of speech communication.

TABLE 3 One-hour Equivalent Sound Level at 150 feet from Roadway

Vehicles per Hour				
Automobiles	Medium Trucks	Heavy Trucks	Speed, mph	Leq(h) dB(A)
1,500	100	200	65	67
1,500	100	200	50	64
1,500	100	0	65	63
1,500	0	0	65	62

Roadway Noise Issues

The federal government does not have an ongoing program to reduce the number of homes exposed to high sound levels from street traffic. Some states independently provide Type II—that is, retrofitted—noise barriers for roadways. The examination of noise and the design of abatement measures usually occur as a requirement of the environmental process for proposed highway construction or for capacity improvement projects.

Several approaches are used to control the noise produced by roadway traffic. Most common is the construction of noise barriers or berms—high, continuous walls or earthen hills—that shield noise-sensitive areas along a right-of-way. To be effective, the barriers or berms must be long—often several thousand feet long—and unbroken.

As a result, berms are feasible only along limited-access highways or long sections of arterials that have few curb-cuts. Most roadway noise analysis and abatement therefore focuses on these types of roads and does not address many of the other types of highly traveled urban or suburban arterials or feeder roads.

Research Projects Target Highway Noise

AMIR N. HANNA

Several National Cooperative Highway Research Program (NCHRP) projects are under way to develop products that will help highway agencies measure highway noise, enhance computer analysis of traffic noise impacts, and identify and implement effective means for reducing noise impacts on nearby communities:

◆ **Measuring Tire–Pavement Noise at the Source** (NCHRP Project 1-44) is developing rational procedures for measuring tire–pavement noise from light and heavy vehicles operating at highway speeds and on all types of paved surfaces.

◆ **Truck Noise Source Mapping** (NCHRP Project 8-56) is applying acoustic measurement and noise source mapping techniques to identify, locate, and quantify noise sources on the typical commercial truck and tractor-semitrailer combinations that operate on U.S. roadways.

◆ **Texturing of Concrete Pavements** (NCHRP Project 10-67) will recommend texturing methods to improve the frictional characteristics of concrete pavement surfaces, with consideration of the effects on noise.

◆ **Highway Research and Technology: International Information Sharing** (NCHRP Project 20-36) supported the participation of professionals from state departments of transportation in a 2004 scanning tour that reviewed how other countries are using quiet pavements to mitigate highway noise (see article, page 16). The tour was part of the International Scanning Program of the American Association of State Highway and Transportation Officials, NCHRP, and the Federal Highway Administration.

PHOTO: FHWA

Scan group inspects the sound intensity setup on light vehicle at French test track.

The author is Senior Program Officer, TRB Cooperative Research Programs, 202-334-1892, ahanna@nas.edu.

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Updated Guides for Controlling Highway Noise

HARVEY S. KNAUER

The Federal Highway Administration (FHWA) published the *FHWA Highway Noise Barrier Design Handbook* with accompanying CD-ROM and video in February 2000 and is preparing to release the *FHWA Highway Construction Noise Handbook* with accompanying CD-ROM in early 2006. Both titles were developed by the Acoustics Facility at the John A. Volpe National Transportation Systems Center in support of the FHWA Office of Natural Environment.

The *FHWA Highway Noise Barrier Design Handbook* package reflects improvements and changes in noise barrier design since the original 1976 publication, addressing acoustical and nonacoustical issues associated with highway noise barrier design. Handbook topics include

- Overview, historical perspective, and terminology;
- Acoustical considerations of noise barrier design, including a brief discussion of performance;
- Noise barrier types, descriptions, and special features;
- Noise barrier materials, including surface textures;
- Aesthetics;
- Utility, structural, and safety considerations;
- Product evaluation;
- Installation, maintenance, and cost considerations;
- Typical design processes;
- Assessments of effectiveness, including performance, costs, and community acceptance; and
- Tools and information resources to aid in design.

PHOTO: FHWA

The handbook and the associated material do not represent FHWA policy on noise abatement but are intended as an aid to agencies, organizations, and individuals involved in noise barrier design. The materials present a variety of considerations in the design of noise abatement features but do not promote or recommend any particular type of barrier feature.

The *FHWA Highway Construction Noise Handbook* package also reflects advances since the original 1976 publication, covering acoustical and nonacoustical issues associated with highway-related construction noise. Topics include

- Introduction, background, and terminology;
- Effects of construction noise on humans and wildlife;
- Construction noise criteria and metrics;
- Operations and equipment for measuring construction noise, including the processing and interpretation of data;
- Prediction of construction noise, including methodology and impact evaluation;
- Mitigation of construction noise at the source, along the path, and at the receptor, including consideration of the time period, the duration of operations, and enforcement-related issues, as well as contract specifications and provisions;
- Data for construction equipment noise levels and ranges for both stationary and mobile equipment;
- A compendium of construction noise experiences, including a searchable database and contacts;
- Related training materials, including manuals, training programs, and references;
- Public involvement during the project phase, using a variety of techniques; and
- Interagency, intra-agency, and other coordination.

Under development with the handbook is a simplified prediction model for noise levels on typical construction projects.

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Because barriers can cost up to $20 per square foot—or more than $1 million per mile—a significant number of homes must benefit to justify the expenditure. Low-density residential areas—such as rural areas or large-lot suburban locations—are less likely to qualify for barrier construction than are high-density areas.

Moreover, most states will not build a noise barrier without the residents' concurrence. Sometimes a few residents pressure a highway agency, money is allocated, and a study is conducted, but public meetings reveal that a majority of the residents would prefer traffic noise to a long, high wall.

Several state agencies have conducted studies to set priorities for barrier construction; this approach minimizes the number of disputes about which neighborhoods along a highway will have barriers. The method involves measuring sound levels; computing the loudest hours throughout the corridor; determining the barrier locations, heights, and costs; and identifying the number of homes that will benefit in each neighborhood according to the number of decibels reduced.

The policy ranks the neighborhoods by the cost per home benefited. The barriers are built in order of priority, with the timing determined by the availability of funds.

Controlling Roadway Noise

The usual methods for limiting roadway noise include building barriers or berms, establishing traffic controls such as speed limits, altering vertical or horizontal alignment for new roadways, establishing buffer zones along a right-of-way, and using quiet pavement—a recent innovation.

Barriers are the most common solution for protecting outdoor areas, when justified by the cost–benefit. Sound insulation sometimes is chosen, particularly for schools, and quiet pavement is gaining interest, as indicated by many research projects in the United States and abroad (see related articles on pages 16 and 18).

Rail Noise

Rail transportation generates sound and vibration levels that can be significant. Although low-frequency sound from aircraft can produce vibration in structures, and elevated highways or roads on certain kinds of geological formations also can produce vibrations that travel through the ground and affect structures, these circumstances are too rare or too isolated to be included in any routine analysis.

In contrast, rail generates ground-borne vibrations throughout the right-of-way. In densely populated areas, buildings often are located close to the right-of-way or even above the right-of-way for underground transit, so that vibration of structures is likely. Along surface rail lines, the proximity of residences makes the sound levels and the vibrations an issue.

In response to environmental legislation, the Federal Railroad Administration (FRA) and the Federal Transit Administration (FTA) have developed methods to measure, predict, and control noise and vibration from rail and rapid transit. The methods are applied as part of the environmental documentation required for federally funded projects.

Rail Sound Metrics

FRA and FTA have published guidance manuals with step-by-step directions for preparing assessments of

PHOTO: TED CURPHEY

Freight train passes over I-90 at Latah Junction, Spokane, Washington.

PHOTO: CHICAGO-L.ORG

Agencies are addressing noise and vibration from elevated transit rail in urban neighborhoods.

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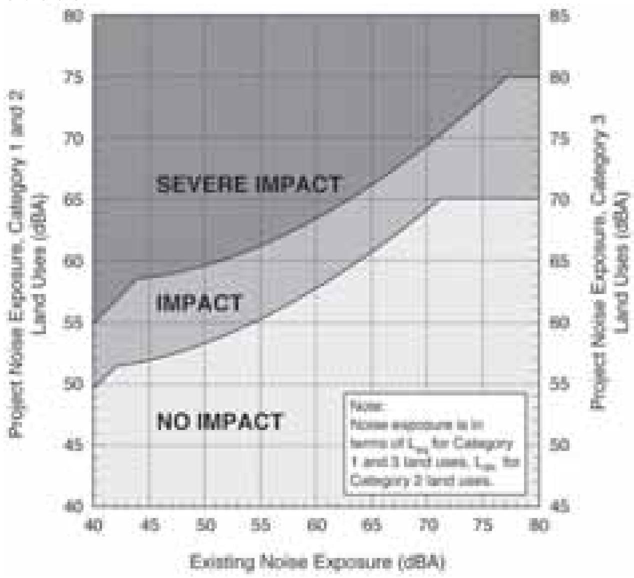

FIGURE 4 Noise impact determination for rail projects.

rail noise and vibration (6–7). Like FAA, both agencies use DNL as the metric to determine the impacts of rail noise; like FHWA, both also use Leq(h).

DNL is used to measure the effects on residences. The Leq(h) for the loudest hour of the day applies to other noise- and vibration-sensitive uses. FRA and FTA identify two levels of noise impact—impact and severe impact—based on the sound levels from the proposed rail project and the sound levels before the project (Figure 4). Table 4 shows some relationships between DNL values and types of trains at different speeds.

Figure 4 shows how rail noise impacts are determined. Category 1 lands require quiet but are used mainly during the day; therefore the sound is measured in Leq(h). Category 2 lands include residences; DNL is the metric. Category 3 lands have institutional uses with daytime and evening activities, which are deemed to be 5 dB less sensitive to project noise than lands in Categories 1 and 2.

Rail vibration impact thresholds are determined from an absolute level. The thresholds of impact depend on the number of events—more than 70 events per day is considered frequent, and fewer than 70, infrequent.

The lowest threshold is for buildings that require a low ambient vibration for operation—for example, buildings with equipment such as electron microscopes or with sensitive manufacturing processes. This lowest threshold is roughly equivalent to the threshold for human perception. Higher thresholds are used for residences and yet higher for institutions with daytime-only uses.

Rail Noise and Vibration Issues

Rail systems include a variety of noise sources—some are associated with the operation of rolling stock, such as locomotives and rail cars, horns and whistles, and wheel squeal on tight curves, but many ancillary sound sources also may contribute. Some are related to rail operations, such as crossing signals, crossovers and switches, substations, and locomotive idling, but others are from the transportation modes that tie into the rail system, such as buses and automobiles at stations and in park-and-ride lots.

Horns for grade crossings can be a problem for nearby residents (see box, page 24). The air horns on freight and some commuter rail locomotives vary in sound levels. Although engineers signal the same “two longs, a short, and a long,” the duration depends on the operator and can affect different numbers of homes along a right-of-way. Current research is examining the use of horns that are permanently mounted at crossings and that sound automatically as a train approaches.

Locomotives often idle for long periods or overnight at termini in suburban areas. Sometimes these idling locations must be moved to accommodate changes in operations or schedules, and residential areas with no previous rail noise exposure are subjected to the sound of an idling locomotive for hours or overnight.

Older engines could not always be restarted and had to idle, but modern locomotives are designed to shut down, sometimes automatically after a period of

TABLE 4 DNL for Different Types of Trains, 50 feet from Track

		Number of Trains per hour		DNL
Type of Train	Speed	Day	Night	at 50 feet
4-car rapid transit	50 mph	20	2	65 dB
4-car rapid transit	20 mph	20	2	60 dB
8-car, 1-locomotive commuter	60 mph	1	0	55 dB
8-car, 1-locomotive commuter	20 mph	1	0	50 dB

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idling, and are quieter as well. Idling not only produces noise but consumes fuel and releases air pollution, adding to the reasons to reduce the idling times.

Controlling Rail Noise and Vibration

If an analysis indicates an impact or a severe impact from rail noise or vibration, mitigation alternatives must be evaluated. On projects that include the purchase of new vehicles, an effective measure may be to develop vehicle design specifications. Other methods to reduce impacts include the design or retrofitting of track support systems, the maintenance of wheels and rails, the construction of noise barriers, and the use of sound insulation for buildings.

When vibration levels are the source of the impact, changing the track support system can be effective—a "floating slab," a resiliently supported concrete slab to which the tracks are fastened; resilient rail fasteners; and resilient mats under the ballast or concrete ties supported by rubber pads are methods to reduce ground vibrations. Subway projects frequently use these techniques. Vibration problems are less common for at-grade and elevated track.

Photo: Wilson, Ihrig, and Associates

Portland TriMet transit rail passes between a sound-absorbing wall and a sound barrier wall.

Sound levels and vibration levels can be reduced by grinding the wheel and rail surfaces. Irregular surfaces, flats produced when wheels lock in stopping, and rough wheels or rails can increase a train's sound and vibration levels. Wheel truing—eliminating flat spots and assuring the roundness of the wheels—and proper grinding of rail profiles can be costly. Rail grinding may require extensive analysis to ensure that the final contours of the surfaces will be durable.

Noise barriers can be effective for at-grade and elevated rail lines. The barriers can be located close to the rail line and need not be high if the wheel–rail interaction is the primary source of noise. On elevated rail lines, barriers 4 feet high can be effective. In addition, if barriers are not feasible—for example, near grade crossings—installing sound insulation in nearby houses may be a solution.

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Quiet Pavement Abroad

Scanning Tour Examines Technologies and Experience

CHRIS CORBISIER

Representatives of the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) participated in an International Scan of Quiet Pavement Technologies, April 30–May 16, 2004, visiting Denmark, the Netherlands, France, Italy, and the United Kingdom. The tour was conducted as part of the International Scanning Program of AASHTO, FHWA, and the National Cooperative Highway Research Program. The 14 participants had experience in noise and pavement issues and included members from FHWA, state departments of transportation, private industry, academia, and the Acoustics Facility at the Volpe National Transportation Systems Center.

In the United Kingdom, TRITON uses a sound intensity setup on a heavy vehicle that can vary loading to the wheel, in line with tire tracks.

The tour documented the state of the practice in design, construction, maintenance, and monitoring of quiet pavement systems and identified innovative practices. In addition, the team gathered information on noise measurement methodologies and monitoring systems.

The group examined sections of single-layer and double-layer porous asphalt on high-speed facilities. On low-speed facilities, thin textured surfaces were found to be successful. Exposed aggregate concrete and diamond-ground concrete sections served well in countries that selected concrete pavement because of climate or other considerations.

Several issues noted during the scan demonstrated the need for further research:

- Which measurement methodology was most effective: close-proximity or sound-intensity measurements at the tire–pavement interaction or measurements from the receptor at the wayside?
- What are the correlations between the close-proximity or sound-intensity methods and the wayside methods of measurement?
- Does the cleaning of porous pavements renew the noise reduction capabilities or does it damage the pavement?
- What are the effects of quiet pavement on light vehicles compared with heavy vehicles?
- How durable are the pavements? Although noise reductions over time were noted for some pavements, many experimental types have not yet demonstrated longevity. Several countries did not have the funds to monitor pavements over time.
- What is the best way to account for noise reduction—as an absolute adjustment or in terms of frequency?
- How can all the many factors that affect noise reduction on a quiet pavement be considered? For example, variations in construction, aggregate selection, climate, vehicle types, binder, pavement temperature, measurement technique, pavement thickness, and typical reference pavement can affect the noise reduction. Moreover, the pavement must satisfy safety and durability requirements before noise reduction capabilities are considered.

Core samples of double- and single-layer porous asphalt from Denmark.

Trailer used in the Netherlands for sound measurement by the close-proximity method.

The scan showed that although quieter pavements can be implemented with success, more research is needed. Each country had different experiences and different conclusions from research, as well as differing environmental and economic considerations.

The scan underscored the need for communication and coordination in the United States, where each state has the flexibility to run its own program. Because quiet pavement research involves many stakeholders, includes many variables, and is in the beginning stages, communication among stakeholders is important. Coordination is essential to avoid errors, assess progress, and guide the research to produce practical results.

FHWA has drafted a memorandum on the research requirements for demonstrating that a pavement qualifies as quiet.[1] By adhering to these requirements, stakeholders will facilitate the accurate comparison of data and trends.

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[1] www.fhwa.dot.gov/environment/noise/qpppeml.htm.

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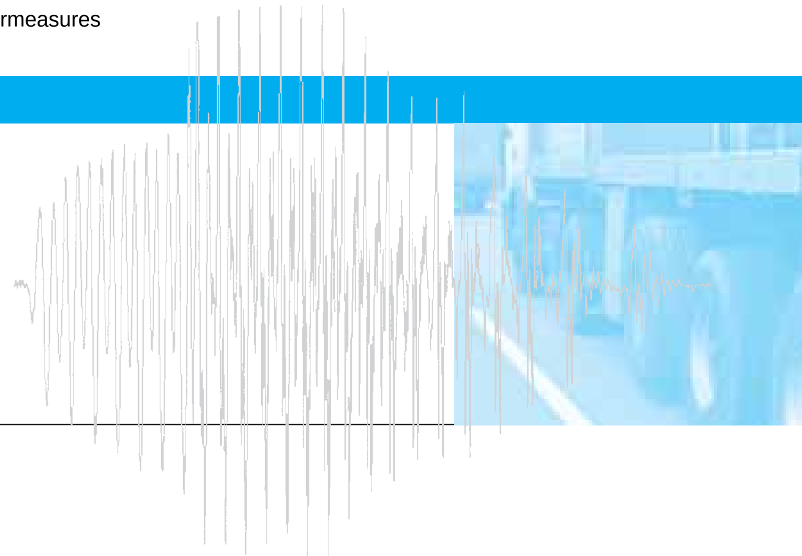

TIRE–PAVEMENT NOISE

Where Does It Come From?

ROBERT J. BERNHARD AND ULF SANDBERG

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Highway traffic noise is generated from four vehicle subsources: the engine–drivetrain, the exhaust system, the aerodynamics, and the interaction of the tires with the pavement (Figure 1). Tire–pavement interaction is the predominant subsource of noise from properly maintained automobiles traveling at speeds above 30 kilometers per hour (20 miles per hour). For properly maintained trucks without engine compression brakes, tire–pavement interface noise is similarly predominant, but at higher speeds. Pavements that produce less noise from the tire interface are a strategic solution for addressing highway noise.

The interaction of the tire with the pavement generates sound that radiates away from the tire in the nearfield, the acoustic transition zone surrounding the source. Tire–pavement noise is complex, and different mechanisms prevail on different pavement surfaces.

At the tire–pavement interface, several mechanisms create energy that radiates as sound. These are called sound generation mechanisms. In addition, some characteristics of the tire–pavement interface cause the energy to be converted to sound and to radiate efficiently. These characteristics are called sound enhancement mechanisms.

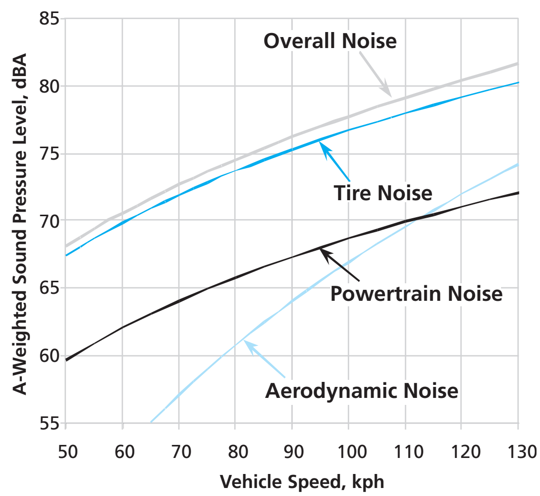

FIGURE 1 Contributions of the various subsources of highway traffic noise: one example (*1*).

Sound Generation Mechanisms

Tread Impact

At the interface of the tire and pavement—referred to as the contact patch—an impact occurs when the tread hits the pavement (Figure 2). The tread impact can be compared to a small rubber hammer hitting the pavement obliquely. This impact causes vibration in the tire carcass—which includes the tread support structure and the sidewall. A similar phenomenon occurs when features of the pavement texture make the tire tread block vibrate.

If the tread block and the pavement are resilient, the energy created by the impact can be reduced. Randomly irregular pavement texture can reduce the repetitiveness of the impact and can decrease the annoyance of the sound.

Air Pumping

The passages and grooves in the tire are compressed and distorted within the contact patch. The air entrained in these passages is compressed and pumped in and out of the passages (Figure 3). The air

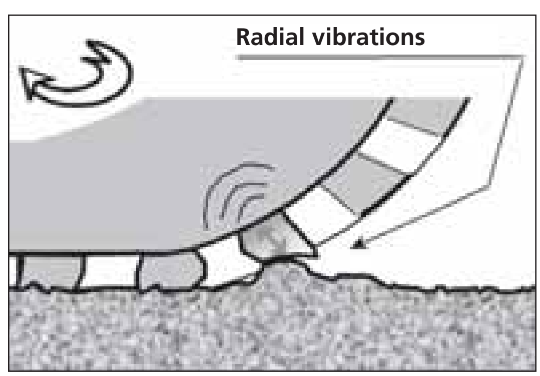

FIGURE 2 Vibration caused by tread block–pavement impact (*2*).

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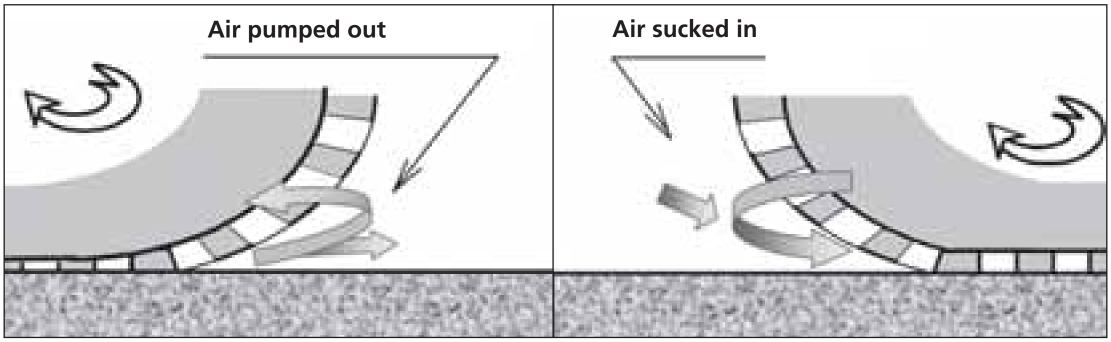

FIGURE 3 Air pumping at (*left*) entrance and (*right*) exit of the contact patch (*2*).

compression and air pumping generate sound—a phenomenon similar to clapping.

Slip-Stick

Within the contact patch, the tread blocks transfer tractive forces from the tire to the pavement, especially in acceleration or braking. In addition, the distortion of the tire carcass in the contact patch imposes horizontal forces on the tread block–pavement interface. If these horizontal forces exceed the limits of friction, the tread block will slip briefly and then stick to the pavement again (Figure 4).

This slipping and sticking happens rapidly and generates noise and vibration. The same phenomenon occurs when athletic shoes squeak on a playing floor in a gymnasium.

Stick-Snap or Adhesion

The contact between the tread block and the pavement causes adhesion—a phenomenon that can be compared to the action of a suction cup. When the tread block exits the contact patch, the adhesive force holds the tread block (Figure 5). The release of the tread block causes sound energy and vibration in the tire carcass.

Institute at Work for Safe, Quiet, and Durable Highways

ROBERT J. BERNHARD

The Institute for Safe, Quiet, and Durable Highways (SQDH) was established in 1998 to integrate education and research in noise and vibration control, pavement design and construction, material design, and traffic management. As a University Transportation Center of the U.S. Department of Transportation's Research and Innovative Technology Administration, the SQDH Institute is developing programs to achieve quiet, safe, durable, and economical highways for automobiles, trucks, and highway-based transit. The programs are expected to have a direct effect on the quality of the environment near highways and an indirect effect on the economics of highway construction and design by reducing the constraints of environmental considerations.

The institute is a joint effort of the Schools of Civil and Mechanical Engineering at Purdue University. An advisory council includes 18 representatives from government agencies, industry associations, and companies involved in highway construction, vehicle manufacturing, and tire manufacturing.

Range of Research

Research projects funded and completed by the SQDH Institute include

- Measurement and Evaluation of Roadside Noise Generated by Transit Buses;
- Development of Porous, Modified Asphalt Mixes for Noise Control Applications;
- Fundamentals of Tire–Pavement Interaction Noise;
- Development of Quiet and Durable Porous Portland Cement Concrete Paving Materials;
- Investigation of Novel Acoustic Barrier Concepts;
- Tire Vibration Behavior Related to Tire–Pavement Noise; and
- Improving Concrete Texturing for Reduced Noise.

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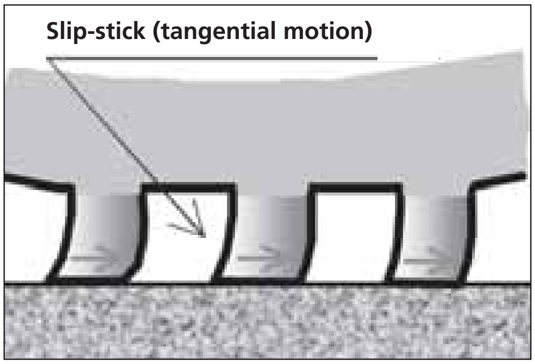

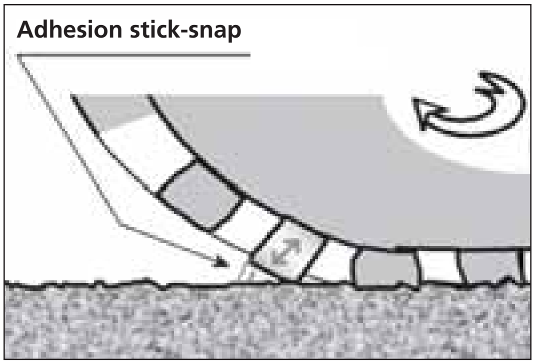

FIGURE 4 (*at left*) Slip-stick motion of the tread block on pavement (*2*).

FIGURE 5 (*at right*) Adhesion between the tread block and pavement at the exit of the contact patch (*2*).

Sound Enhancement Mechanisms

The energy created at the tire–pavement interface does not always radiate efficiently. The tread blocks are small and would not be efficient radiators without the rest of the tire–pavement system. Similarly, air pumping alone would not be a significant source of energy. Several aspects of the tire–pavement system enhance the radiated noise.

Horn Effect

The geometry of the tire above the pavement forms a natural horn (Figure 6). Sound created by any

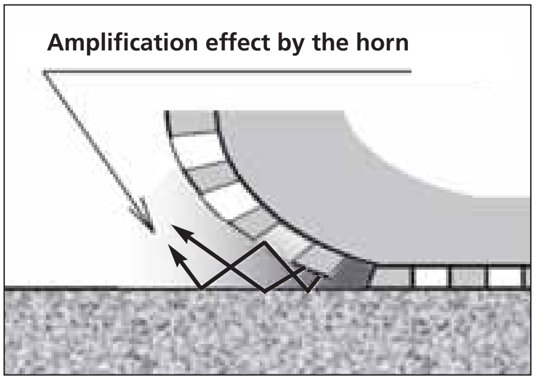

FIGURE 6 Horn effect or amplification created by the tire and pavement (*2*).

Summary reports for each of these projects and others are available on the SQDH Institute website.[1]

The SQDH Institute will host Quiet Asphalt 2005: A Tire–Pavement Noise Symposium, November 1–3, in Lafayette, Indiana. The institute also is participating in a series of 16 "Noise 101" short courses sponsored by FHWA.

Roadmap to Quieter Highways

The SQDH Institute hosted the FHWA Workshop to Develop a Roadmap to Quieter Highways, September 14–16, 2004. The goal is to produce a reliable design specification for pavements that are safe, durable, and cost-competitive, as well as substantially quieter than current pavements.

When this design goal is achieved, policy changes may be implemented to permit the use of quiet pavement as a noise mitigation alternative and to incorporate pavement characteristics into noise predictions. The roadmap and the workshop proceedings are available on the SQDH website or in hard copy from the Institute. A second roadmap workshop is scheduled for spring 2006.

[1] widget.ecn. purdue.edu/~sqdh/.

Tire–Pavement Test Apparatus

The SQDH facility is equipped with a tire–pavement test apparatus (TPTA) for laboratory-based measurements of the noise generation characteristics of tire–pavement combinations. The TPTA consists of a stationary drum with six pavement samples and a rotating arm with a tire mounted at each end.

TPTA apparatus.

The drum diameter is 12 feet (3.66 meters). The length of each pavement specimen is approximately 1/6 of the circumference. The current design pavement specimen is 8 inches (203 millimeters) thick. Up to 1,000 pounds (4.4 kilonewtons) of normal pressure may be applied to each tire, simulating a 2-ton vehicle. The speed of the two counterbalanced tires varies up to a maximum of 30 miles per hour (48 kilometers per hour). Sound measurements can be made on the tire, in the pavement, and with microphones that move beside the tire.

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Practical Considerations for Quiet Pavements

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Recent research and experiences in the United States and abroad have increased interest in quiet pavement for noise mitigation. Quiet pavement can be an alternative or a supplement to more traditional abatement measures such as noise barrier walls and berms.

This type of mitigation often becomes attractive when initial costs, aesthetics, and other benefits are considered—such as improved drainage and reduced spray in wet road conditions. Often lost or ignored in the enthusiasm for quiet pavement as a solution to the highway noise problem are some stark realities and practicalities.

Performance Commitments

When noise abatement construction is part of a project, the details—such as the resultant noise levels, insertion losses, and abatement costs—are specified in the project's environmental and design documents. Analyses are based on design-year traffic projections and indicate that the noise levels and insertion losses will be maintained at least through the design year.

With the traditional noise barrier abatement techniques, these commitments can be assured. Assuring similar continuing performance for a quiet pavement abatement technique, however, requires regular testing, because the acoustical benefits may deteriorate; also required is the highway agency's commitment, backed by funding, to maintain the acoustical properties of the pavement in perpetuity.

Maintenance Issues

State highway agencies must be aware of the quiet pavement's performance under the weather conditions in the area. Warm-weather states must focus on the effects of constantly higher temperatures. States in northern climates must consider the effects of snow and ice, as well as of the treatment and removal operations such as salting and plowing. Moderate climate areas may have freeze–thaw cycles that affect pavement durability. States also must consider the manpower and costs of cleaning the pavement surfaces, if necessary to maintain the acoustical properties.

Vehicles and Barriers

Although vehicle types are considered in the design of quiet pavements, the emphasis most often is on the mitigation of tire–pavement noise.

PHOTO: DAVE NEWCOMB

Quiet pavement in the Netherlands.

This may be appropriate for highways with low or no truck volumes; however, the influence of heavy trucks must be addressed when noise abatement options are compared. In addition, the real and perceived benefits of a noise barrier blocking the line of sight to the noise source must be considered, even if a quiet pavement alternative offers equal potential for noise attenuation.

On some projects, quiet pavements may be able to meet the state highway agency's goals for recommended insertion loss. Other cases may require a combination of quiet pavements and noise barriers. A combination may reduce tire noise and background din, but with a lower noise barrier than would otherwise be required. Yet if the barrier is not high enough to block higher truck noise sources, such as exhaust stacks and refrigeration units, residents may perceive these sounds as more noticeable, creating a public relations problem for the state highway agency.

Benefits to Motorists

Requests for the construction of quiet pavements often originate from vehicle operators and not from neighborhood residents. In the early days of open-graded pavement—placed to improve drainage, not to reduce noise—some drivers in Canada pulled off the road to check their engines. On the Pennsylvania Turnpike, a billboard advertising the quiet aspects of bituminous pavement was directed primarily at motorists, not at the adjacent property owners. Additional support for the construction of quiet pavements, therefore, may be gained by focusing on the acoustical and other benefits to motorists.

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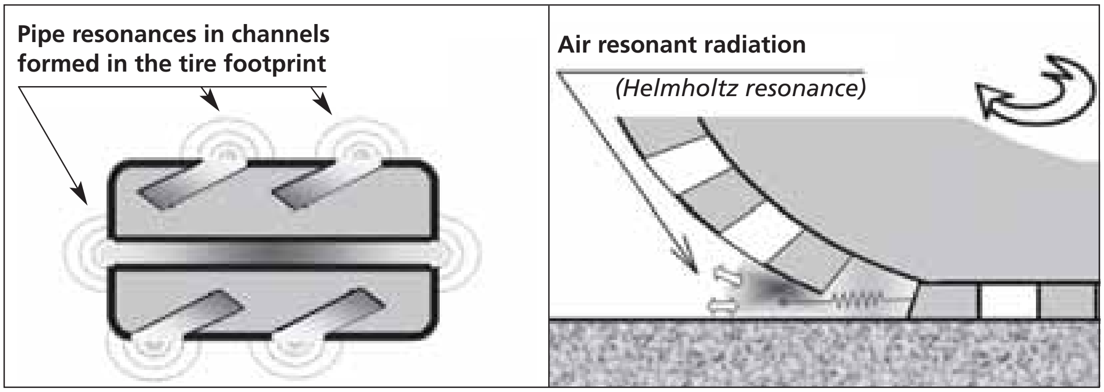

FIGURE 7 Sound amplification caused (*left*) by organ pipe resonances in channels in the tire footprint, and (*right*) by Helmholtz resonator geometries within the contact patch (*2*).

source mechanism near the throat of the horn is enhanced as if by a horn.

Organ Pipes and Helmholtz Resonators

The tread passages of the tire in the contact patch take on the shapes of acoustical systems that enhance the generation of sound. These include organ-pipe resonances, as well as Helmholtz resonances, similar to the whistle produced by blowing across an open bottle (Figure 7).

Carcass Vibration

The vibration energy created at the tire–pavement interface is enhanced by the tire carcass. Vibrational waves propagate in the tread band, the structural element of the tire adjacent to the tread blocks. These waves create sound that radiates from the tire carcass. In addition, the sidewalls of the tire carcass near the contact patch vibrate and radiate sound.

Internal Acoustic Resonance

The air inside the tire also responds to the excitation of the tire. At frequencies associated with the natural frequency of the toroidal enclosure inside the tire, the air inside the tire will resonate. The resonance is sufficient to be audible.

Comprehensive Strategies

Tire–pavement noise is a challenging problem. The four sound generation mechanisms for tire–pavement noise depend on certain combinations of tire and pavement. Different source mechanisms may dominate in generating sound for different applications, making it difficult to develop strategies that would reduce the source generation in all cases. In addition, if the source mechanisms are similar in strength, a strategy that suppresses one will not have a dramatic effect on the total noise level, because the other mechanisms will continue.

The enhancement mechanisms also complicate strategies for reducing tire–pavement noise. The contributions from the various sound enhancement mechanisms are often difficult to distinguish from each other or from the source mechanisms. The enhancement mechanisms for different surfaces and conditions may not always be clear. Many of the mechanisms that generate or enhance the sound from tires and pavement are integral to the tire and pavement characteristics required for safety, durability, and cost-efficiency.

Tire–pavement noise solutions are not straightforward. Nonetheless, significant reductions of noise from the tire–pavement interface have been demonstrated and remain a promising strategy for achieving quieter vehicles on quieter highways.

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TRANSIT RAIL NOISE AND VIBRATION

Research on Track with New Controls

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The prediction and control of noise and vibration from transit rail transportation present multifaceted problems involving vehicle motion, wheel–rail interaction, associated contact mechanics, propagation through the air and the ground, diffraction over barriers, absorption, and transmission into structures. The topics draw on a range of knowledge and experience in acoustics and noise control engineering and motivate both pure and applied research.

Historical Perspective

With the Noise Control Act of 1972 and the Environmental Protection Agency's recommendations for noise levels "to protect the public health and welfare," interest in rail transportation noise and vibration increased. The U.S. Department of Transportation's Transportation Systems Center (TSC)—now the Volpe National Transportation Systems Center—funded considerable amounts of research.

As a result, the 1970s and 1980s can be termed the golden years of domestic research in rail transit noise and vibration. TSC issued summary reports (*1, 2*) and oversaw research on the prediction and control of noise from aerial or elevated structures (*3*), wheel–rail interaction and noise radiation (*4, 5*), the isolation of vibration with floating slab track (*6*), vibration propagation, vehicle interior noise (*7*), and wheel–rail noise control treatments at the Southeastern Pennsylvania Transportation Authority (*8*).

PHOTO COURTESY OF CHICAGO-L.ORG

Interest in ground-borne noise and vibration prediction and control increased with the construction of new transit systems in Washington, D.C., San Francisco, Atlanta, and other cities during the 1970s and 1980s. The Urban Mass Transit Administration (UMTA), predecessor to the Federal Transit Administration (FTA), funded studies on ground-borne noise and vibration control during this period (*9*). In the late 1980s, UMTA sponsored an extensive evaluation of resilient rail fasteners for noise control on the elevated structures of New York City Transit (*10*).

Much of the early research was incorporated into a comprehensive manual for controlling urban rail transit noise and vibration (see box, page 23). The manual described such measures as direct fixation fasteners, floating slab track, and resilient wheels; provided design criteria; and covered some esoteric topics, such as subway pressure transients and substation noise. The results of research on criteria and prediction methodologies later were incorporated into another manual, *Transit Noise and Vibration Impact Assessment*, which has become the guiding document for noise and vibration impact analysis in FTA-funded transit projects (*11*).

More recently, the Transit Cooperative Research Program (TCRP) developed a manual for wheel–rail noise control. TCRP Report 23 provides methods for identifying wheel–rail noise problems and treatments, reviews the costs, and includes a computer program for identifying noise control solutions (*12*).

Transit Agency Approaches

Ground-borne noise and vibration have significant impacts on residences and structures located above or near subway tunnels. In Toronto, vibration propagation coupled with conventional track and rough wheels produced audible ground-borne noise up to 400 feet from the tunnel.

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To counter this, the Toronto Transit Commission adopted a standard for discontinuous floating slab or double-tie track with an isolation frequency of approximately 16 hertz. Tactile perceptible vibration was not a problem, probably because of stiff soils and low resonance frequencies from the vehicles' primary suspension. Several other rail transit systems have installed floating slabs (*13*).

Modern heavy rail transit vehicles incorporate stiff primary suspensions that isolate the vehicle truck from the axle. These suspensions have increased ground vibration levels at frequencies between 20 and 30 hertz, sometimes producing perceptible ground vibration. Vehicles with primary suspensions that use softer materials may reduce the perceptible low-frequency vibration.

Heavy rail and light rail transit systems have been making use of abandoned railroad lines for new track. This practice places new alignments near homes and other structures, increasing the demands on noise and vibration control technologies. Transit systems have performed detailed studies of noise and vibration control options and possible mitigation costs for these alignments, advancing the state of the art in noise prediction modeling.

Modeling and Data

Before 1990, the prediction of ground-borne noise and vibration and the design of treatments were limited by affordable computing power. Early efforts at vibration propagation modeling were mostly heuristic.

Today the acoustician or noise control engineer must consider shear waves, Rayleigh waves, soil–structure interaction, and the like, drawing on theories developed by geophysicists and earthquake engineers for wave propagation in soils and rock and for soil–structure interaction. In addition, several commercial software packages allow finite ele-

Photo: Doug Grotjahn

Noise Program Heard Worldwide

Jeffrey G. Mora

The Urban Mass Transportation Administration (UMTA)—the predecessor to the Federal Transit Administration—developed the Rail Noise and Abatement Program in the early 1970s. The agency conducted a survey of rapid and light rail systems in the United States and Canada to identify the most urgent needs for the UMTA Rail Research Program to address. Noise was the number one problem cited by the rail systems surveyed.

Photo: Bruce Morrill

PATCO has applied noise controls and vibration reduction measures since opening in 1969.

Older conventional transit systems in New York, Boston, Chicago, and Philadelphia had some steel elevated lines, which had never undergone significant noise reduction measures. The first post–World War II new rapid transit systems applied noise and vibration reduction techniques, which then were advancing rapidly; these included the Philadelphia-area Port Authority Transit Corporation (PATCO), which commenced service in 1969, and San Francisco's Bay Area Rapid Transit (BART) system, which opened in 1972.

When UMTA's Rail Noise and Abatement Program was starting up, rubber-tired rapid transit systems were a topic of considerable debate. Were the systems, such as a line in Paris, quieter than conventional steel-wheeled rail systems?

BART railgrinder used to reduce noise levels.

The UMTA noise research program was transferred to the U.S. Department of Transportation's Transportation Systems Center—now the Volpe National Transportation Systems Center—for program development and implementation, working in conjunction with a technical committee of what is now the American Public Transportation Association. The focus of the program was to reduce noise from rolling stock and from the structures on which the rolling stock operated.

The most significant product was the breakthrough *Handbook of Urban Rail Noise and Vibration Control*, published in 1982. This engineering handbook was adopted by transit operators and consultants for successful short- and long-term efforts to reduce noise and vibration from urban rail transit systems; the handbook has gained use worldwide.

The author retired in 2004 as Transportation Systems Manager, Office of Research, Federal Transit Administration, where he worked for more than 33 years.

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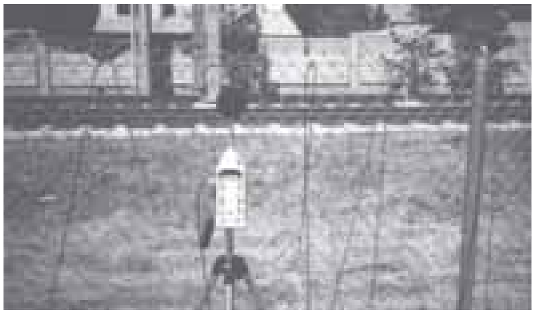

Measuring sound at tangent track, Portland Metro.

ment modeling of soil–structure and vehicle–track interactions.

The transfer function testing method, described in the FTA guide (*11*), has been augmented with the forward seismic modeling of layered soils, using soil moduli obtained by vertical shear and compression wave velocity profiling or seismic refraction (*14, 15*). These test procedures, used by geotechnical engineers to determine soil properties, are common for soil investigations on transit system projects.

Acquiring the data, however, may involve drilling, seismic refraction, vertical shear wave profiling, and other subsurface investigations. In situ propagation testing has circumvented this problem to some extent, by determining the so-called line source responses and force density levels (*16*). The procedure is part of FTA standard practice (*11*).

Researchers in Europe and the United Kingdom have developed noise prediction models for rail transit. A computer program called TWINS includes parameters such as wheel and rail properties, rail fastener characteristics, and rail and wheel roughness, for predicting wayside noise levels.

Tracks for Research

Although the prediction and control of rail transit noise and vibration have progressed substantially in the past 30 years, research is needed in several areas.

Wheel Squeal

Lubrication is the most effective treatment for wheel squeal in light and heavy rail transit systems. Many products are available, including friction modifiers, Teflon-based lubricants, vegetable-based lubricants, and conventional grease. Friction modifiers and vegetable-based lubricants are gaining in use. Conventional grease can contaminate the soil and may affect braking.

Wheel vibration absorbers and ring dampers have been effective in controlling squeal. Other initiatives may yield practical benefit. Researchers at TNO in the Netherlands have identified a positive feedback mechanism, when the wheel–rail contact patch slips laterally, as the cause of wheel squeal. This may indicate that maintaining wheel and rail profiles and lateral compliance of the rail may help to control wheel squeal.

Communities Allowed to Silence Train Horns

Communities nationwide can silence train horns at highway–railway grade crossings and retain bans on train whistles, under a new regulation by the Federal Railroad Administration (FRA).[1] The rule allows communities flexibility to establish or maintain quiet zones while keeping highway–railway grade crossings safe for motorists. Issuance of this regulation follows years of discussion and analysis of ways to maintain crossing safety in quiet zones.

The train horn rule went into effect on June 24, 2005, the result of a 1994 law mandating the use of the locomotive horn at all public highway–railway grade crossings, with certain exceptions. The regulation provides for six types of quiet zones, ensures the involvement of state agencies and railroads in developing quiet zones, gives communities credit for pre-existing safety warning devices at grade crossings, and addresses other issues, including pedestrian crossings within a quiet zone.

The establishment of a new quiet zone requires the installation of flashing lights and gates—as well as additional safety measures, if needed—at each grade crossing. Quiet zones can be in effect around the clock or overnight between 10 p.m. and 7 a.m.

Communities with whistle bans that were in effect on October 9, 1996, will be able to keep train horns silent for another 5 to 8 years. In the meantime, the community must plan for and install any additional necessary safety measures. Communities that banned whistles after October 9, 1996, and before December 18, 2003, have 1 year to install any additional necessary safety measures.

The rule also establishes a maximum volume level for train horns and reduces the amount of time the horn can be sounded, which will benefit communities that decide not to establish quiet zones.

[1] Final Rule on the Use of Locomotive Horns at Highway–Rail Grade Crossings (FRA-1999-6439-3923), http://dms.dot.gov/. For additional information, www.fra.dot.gov.

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Sound-absorbing wall shields residences from noise generated by Portland TriMet transit rail.

Another possible avenue for research is to decrease the angle of attack on short-radius curves by maintaining or reducing the gauge. Gauge widening is common in track design—a holdover from railroad curves that had to accommodate locomotives with three-axle trucks. The need for gauge widening on light rail and heavy rail transit systems, however, is not apparent.

Maintaining or reducing gauge would avoid an excessive angle of attack and possibly reduce the propensity for squeal, especially with lubrication. Reduced wear of flanges and gauge faces may be a major benefit of this research.

Rail Undulation

Rail undulation may contribute to wayside vibration at frequencies below 12 hertz. The effects of rail straightness and of radial run-out—or variations in the wheel circumference—on low-frequency vibration need to be quantified. The American Railway Engineering Association specifications for rail straightness address only rail upturn at the ends and establish no limit for rail undulation in the lengths supplied by the steel mills. A rail undulation introduced in manufacturing cannot be removed easily by grinding after installation.

Ground Vibration Criteria

Criteria for the impact of vibration on humans have been controversial because of the cost of mitigating low-frequency vibration. FTA criteria employ a measure of vibration velocity that derives from the International Organization for Standardization and the American National Standards Institute (ANSI) recommendations for building vibration (*11*). FTA is considering a relaxation of the criteria, however, to match the ANSI standards for final design; transit systems in Portland and San Francisco have applied this approach successfully. Research is needed to review the vibration criteria in the context of operational experience in the past 20 years.

New alignments of light rail or heavy rail systems may pass near university or industrial research facili-

Testing Out an Idea for Quieter Railway Roadbeds

CHARLES TAYLOR

A layer of rubber-modified asphalt concrete (RMAC) under the track ballast may improve the durability of the track and may reduce the rail deformation, vibration, and noise generated by high-speed trains. A recent project under the High-Speed Rail Innovations Deserving Exploratory Analysis (IDEA) Program investigated the effectiveness of the technique.

Currently only ballast, concrete, or asphalt concrete are used as underlays for tracks. RMAC is a mixture of commercially available asphalt concrete with crumb rubber from discarded tires.

Preliminary studies indicate that the damping ratio—which indicates the potential for absorbing vibration—is 6 percent to 11 percent for RMAC, compared with 2 percent to 3 percent for compacted soil, and 3 percent to 4 percent for conventional asphalt concrete. In addition, the stiffness of RMAC is two to three times higher than that of typical compacted soil. These findings indicate that RMAC can reduce the pressure on soil subgrade, reducing in turn the vibration passing from trains into the environment.

In numerical simulations, RMAC reduced vibrations by about 30 percent; the reduction with conventional asphalt concrete was approximately 10 percent. A series of laboratory tests was designed to measure the stiffness and damping ratio of RMAC under loading conditions associated with typical axle loads, as well as the durability of RMAC under a range of environmental and railroad operating conditions.

Computer simulations also were performed to investigate the influence of the depth and thickness of the RMAC layer on performance. For comparison, simulations were performed on the same system without the RMAC layer.

The IDEA product included specifications, performance assessments, and cost estimates. The high-speed railroad industry can use these to determine where and how to install RMAC in track structure. An RMAC layer may be installed under railroad tracks or under a test track at the Transportation Technology Center in Pueblo, Colorado, to evaluate vibration and noise attenuation under a range of operating and weather conditions.

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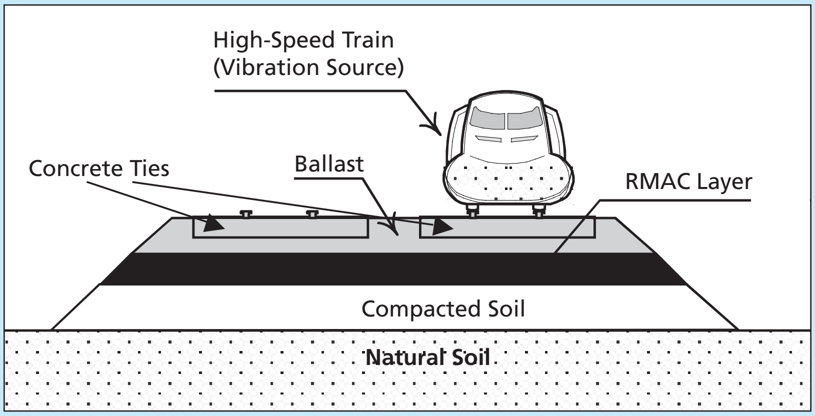

Schematic for location of RMAC layer.

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Top: Examining the dynamic response of transit rail wheel fitted with vibration absorbers. *Middle*: Portland Max light rail transit track with vibration-absorbing devices. *Bottom*: Lubricating spray applied to transit rail at curve on Portland TriMet track to prevent wheel squeal.

ties that require a vibration-free environment—for example, facilities for nanotechnology research. The criteria for vibration near research laboratories also should be reviewed and improved.

Grade Crossing

Grade crossing continues as an issue for railroads and transit. Local warning devices have been investigated, and four-quadrant gates—which prevent cars from driving around lowered gates—have been installed to establish quiet zones. Follow-up work on the effectiveness and on the impact on safety should be continued.

Research Already on Track

TCRP has conducted research on transit-related noise and vibration control. Recent projects include the following:

◆ Joint Track-Related Research with the Association of American Railroads–Transportation Technology Center, Inc. (TCRP Project D-7), applies technologies developed in railroad research—such as the control of wheel squeal by modifying the rail surface and by top-of-rail lubrication with a through-the-rail lubricator—to the transit industry.

◆ Center Truck Performance on Low-Floor Light Rail Vehicles (TCRP Project C-16) is examining the independently rotating wheels in the center truck of low-floor light rail vehicles. The wheels do not promote curving, which increases the angle of attack and causes flange and gauge face wear, as well as noise. The research addresses not only noise and vibration, but also derailment, flange and gauge face wear, and ride quality.

◆ Ground-Borne Noise and Vibration in Buildings from Rail Transit (TCRP Project D-12) will investigate criteria for human exposure to vibration and will propose appropriate adjustments for rail transit.

The European Union is establishing noise rules for all rolling stock that travels across international boundaries. The research includes topics applicable to rail transit: wheel–rail interaction and radiation, ground vibration modeling and prediction, and wheel and rail maintenance.[1]

Next Destinations

Research and development in transit rail noise and vibration continues to be active and challenging. Controlling railway noise and vibration is increasing in importance as transportation corridors compete for space with residential and industrial structures, and as manufacturing and research probe the frontiers of nanoscience.

[1] Much of this research is presented at the International Workshop on Railway Noise, held every 3 years; papers are published in the *Journal of Sound and Vibration*. Railway noise and vibration also are topics at InterNoise, sponsored by the Institute for Noise Control Engineering.

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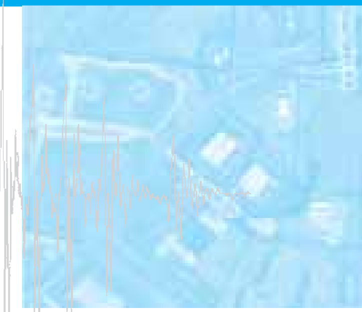

HIGHWAY TRAFFIC NOISE AND LAND USE DEVELOPMENT

Coordinating Federal, State, and Local Authorities

KENNETH D. POLCAK

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The National Environmental Policy Act (NEPA) mandated the establishment of regulations and standards by federal agencies to assess environmental impacts and to protect the environment. The signing of NEPA into law on January 1, 1970, concluded more than a decade of debate, discussion, and refinement of the principles, policies, and approaches to assessing environmental impacts.

Two additional major legislative actions mandated more specific guidance, policy, and criteria related to environmental noise. The Federal-Aid Highway Act of 1970 required the Federal Highway Administration (FHWA) to establish environmental impact assessment standards, procedures, and criteria. The Noise Control Act of 1972 established a national policy "to promote an environment for all Americans free from noise that jeopardizes their public health and welfare."

The Noise Control Act also divided powers or responsibilities between the federal, state, and local governments. The federal government is responsible for noise source emission control and for providing assistance, support, and guidance to state and local governments. State and local jurisdictions, in turn, regulate and control noise sources and the levels of noise permitted in the environment (*1*).

Proactive Approach

The division of power and responsibility has evolved into a three-pronged approach to the control and abatement of environmental noise. Effective control of the adverse effects of highway traffic noise requires

- Quieting the source—that is, the vehicles;
- Considering and implementing abatement of noise impacts from highway projects; and
- Controlling land use near highways (*2*).

The federal government's role is to regulate noise emissions from vehicles. The states, which implement and maintain the highway infrastructure, must analyze and address the potential noise impacts of proposed highway projects that would be adjacent to noise-sensitive land uses. The local government has control over land use decisions—where development is permitted and what type of development is allowed.

Successful land use planning and noise-compatible development requires a proactive approach at the local government level. The goal is to avoid problems before they are created and to eliminate after-the-fact mitigation from transportation projects.

The local planning agency must make a commitment to work with the development community to consider the need for—and the benefits from—developments that are compatible with prevailing noise conditions. In addition, state and federal authorities must provide the tools, resources, and support.

The role of the state and federal governments is to serve as advocate and supporter, and the role of the

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Getting a Good Read on Traffic Noise Control and Land Use

The Audible Landscape: A Manual for Highway Noise and Land Use. Office of Research and Development, Federal Highway Administration, November 1974.

Entering the Quiet Zone: Noise-Compatible Land Use Planning. Federal Highway Administration, May 2002.

Guidelines for Considering Noise in Land Use Planning and Control. Federal Interagency Committee on Urban Noise, June 1980.

Highway Traffic Noise in the United States: Problem and Response. Federal Highway Administration, April 2000.

Policy on Land Use and Source Control Aspects of Traffic Noise Attenuation. American Association of State Highway and Transportation Officials, Washington, D.C., March 1980.

local government or agency is to serve as the primary regulator and controlling authority. The developer and consultant must address and satisfy the regulatory requirements through engineering design and analysis in the context of business and profitability (see sidebar, page 29). The degree of cooperation and collaboration between the partners determines the level of success.

Assessing Noise Impacts

Under the NEPA regulations, state government officials responsible for transportation infrastructure development must assess the potential environmental impacts—including the noise levels—not only on current land uses, but also on undeveloped land. This information can guide or influence development and can reduce the need for future expenditures for noise abatement.

FHWA regulations require the state highway agency to supply the results of highway project noise studies to local planning officials. The studies provide general information on future noise levels, including data related to undeveloped land.

An impact zone—a corridor along the highway—may be defined to show the locations in which noise levels would be above a certain threshold as a result of proposed highway improvements. The information should assist local officials in determining where certain types of development are appropriate and should support mitigation strategies. The width of the impact zone helps determine, for example, the minimum setback distances for the placement of structures or activity areas.

The data are advisory. Whether local officials use the noise level data to full potential in land use planning decisions is outside the influence of state or federal agencies, and the extent of use cannot be gauged. Local planning agency officials must view the information as vital and useful for determining the types of development that should be allowed.

Federal Resources

From the earliest days of the modern environmental movement, the federal government has promoted land use planning as a tool to prevent or minimize noise impacts, through publications and other tools supporting the states' role (see box, top left). Although some of the documents date back to the 1970s, the information and concepts remain applicable for guiding local governments in the control of land uses adjacent to highways. The objective is to guide noise-sensitive uses away from noisy highways and to encourage land uses not sensitive to noise.

What Is a Type II Project?

Federal Highway Administration (FHWA) regulations provide the mechanisms, procedures, and guidance for addressing the impacts of noise and the mitigation of noise along existing and proposed highways. FHWA regulations define two types of projects:

- Type I projects involve new highway construction or proposed improvements to highways. The consideration of noise impact and potential mitigation is mandatory during the project development process.
- Type II projects address noise within a community along an existing highway that has no improvements proposed. Type II consideration is not mandatory; each state can choose whether or not to pursue a Type II project.

The regulation provides a way for state transportation agencies to address the noise impacts of highway construction projects that predated the NEPA process and to implement noise abatement if warranted. Communities that predate the highway may be eligible for the retrofitting of noise barriers.

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Highway-Compatible Residential Development

A Feasible Ideal

MICHAEL A. STAIANO

"If you build it, they will come" is a quotation often applied to highways and residential development. People choose dwellings close to highways to get to work and to return home as easily as possible. Accessibility is considered "essential for successful development" (*1*).

In the Washington, D.C., area, "people are standing in line" to buy million-dollar-plus homes next to Interstate highways (*2*). Consequently, new communities line the highways, although office and commercial development is more compatible with traffic noise.

Finding a Balance

Local planning and zoning authorities must accommodate an appropriate balance of land uses, making highways through residential zones unavoidable. Clustering residential construction along these corridors is convenient for commuting and minimizes the cost of providing infrastructure for new development—water and sewer services, as well as local and connecting streets.

Moreover, property owners' development rights and developers' clever schemes often are difficult for local authorities to resist. The issue is not whether there will be residential development, but how the design can provide for an acceptable quality of life for residents while still allowing the developer a reasonable profit.

In the United States, most highway noise abatement takes the form of noise barriers constructed by the state, often with the federal government sharing the costs. Developers and local planning and zoning authorities are recognizing the need to mitigate traffic noise for new residential developments.

Some jurisdictions have understood that development adjacent to highways requires special consideration. Others have addressed the matter later—prompted by a state highway department unwilling to build new barriers unless the jurisdiction controlled the development along roadways.

Ideally, restricting development to noise-compatible uses can avoid noise impacts. This cannot always be accomplished—and some land planners perceive the practice as undesirable, creating strip development. As a result, the objective becomes highway-compatible residential development.

Demands on Developers

The goal of a developer is to maximize profit by building the greatest number of housing units allowable for the zoning. The allowable maximum density, however, is usually unattainable because of

- Geometric restrictions for individual lots and buffer zones for adjacent properties;
- The need for roads, sidewalks, vehicular parking, recreational space, and other amenities;
- Drainage, stormwater management, and tree conservation requirements; and
- Floodplains, wetlands, and steep slopes.

Berm construction is generally preferred by builders.

Developers are not enthusiastic about setting aside developable land to serve as a noise buffer, especially if the buffer does not satisfy other constraints, such as tree conservation. As a result, highway-compatible site design becomes a trade-off between losing lots and accruing costs for noise mitigation.

Although many developers recognize that minimizing noise exposure enhances the value of a housing unit, the benefits are harder to quantify than the costs. The costs can be direct, such as barrier construction, as well as indirect, such as the reduced revenue from lost building lots. The benefit of an increased selling price is difficult to determine, because the proximity of the highway has positive and negative aspects.

Studies of traffic noise and property values show that the selling price of a house in a noisy area is about 0.4 percent less per decibel than the selling price in a quiet neighborhood—a difference of $32,000 for a $400,000 house (*3*). In an active housing market, however, the increase in selling time for houses next to a noisy highway may be negligible. Market forces thus can be insufficient as controls. As a result, the assurance of highway-compatible residential development becomes the responsibility of the local planning and zoning authority, which approves land subdivision and development.

The land development process starts when a developer proposes a plan responsive to the local requirements, and the planning and zoning authority reviews the proposal. Noise evaluation and control should occur within this framework. The local jurisdiction must

- Establish reasonable design criteria,
- Define a consistent evaluation process, and
- Competently review the developer's submittals.

In response, the developer must

- Estimate the traffic sound levels at the site,
- Design noise mitigation features, if necessary, and
- Document the design analyses for review.

(continued on next page)

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Highway-Compatible Residential Development

(continued from page 29)

Where to Mitigate?

If a tree falls in the woods with no one there to hear it, it makes sound, but not noise. Noise is unwanted sound and therefore requires the presence of a person to object. Residential development should focus noise mitigation on areas where people are present.

Controlling noise at the perimeter of a 10-acre lot produces little benefit, but quieting a backyard patio or deck is essential for a single-family residential development. A multifamily development, in contrast, is less likely to make use of the outdoors, and noise may be mitigated appropriately with architectural soundproofing to protect residents indoors. Balconies on highway-exposed façades, however, should be enclosed, and outdoor amenity areas should be sheltered, perhaps by the building structures.

The orientation of a dwelling may ensure a congenial outdoor area. Fronting a dwelling to a noisy roadway can shield the rear patio or deck; a brick-veneer front façade, for example, can provide the most soundproofing benefit.

Locating active recreation areas—ball fields, tennis courts, and golf links—and tree conservation zones between the road right-of-way and dwellings can enhance the compatibility of a residential development with an adjacent highway. Clever use of the topography, suitable regrading, and placement of auxiliary structures—such as parking facilities—can minimize barrier requirements.

Site constraints and market forces limit these options, however. Noise barriers and structural soundproofing may be necessary if a site is sufficiently exposed. If barriers are indicated, berm construction generally is preferred. Builders are accustomed to moving earth but are loath to construct walls without enclosing a space on four sides with a roof above.

Answering the Challenge

Many communities have achieved highway-compatible residential development. Consistently successful outcomes, however, demand well-written and intelligently implemented regulations. This requires sophistication on the part of local planning and zoning authorities, not only to set reasonable and appropriate goals but also to determine if a developer's plan for noise mitigation is feasible and if the analysis is competent.

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FHWA recently initiated a series of workshops on noise-compatible land use planning to encourage and support the concept (see box, page 31).

States as Advocates

Examples of state-specific activities, historical and ongoing, illustrate how some agencies have attempted to advance the cause of effective land use planning and noise-compatible development. Some approaches are strictly supportive; others present incentives for local jurisdictions to embrace the concept and to implement programs.

Maryland Initiatives

Maryland has a long history of land use planning. Studies and research efforts have led to the establishment of many effective local land use control programs and regulations.

In the early 1980s, the Maryland State Highway Administration (SHA) participated in a research project, cosponsored by FHWA, to identify and compare preventive planning techniques and to provide noise measurement techniques for local jurisdictions that had limited technical capabilities (3). One of the results of this research was the development of noise

contours for selected highways with substantial traffic volumes. The study recognized that effective control and consideration of noise from the major highway systems was feasible, practical, and fiscally responsible for a county with considerable potential for development and growth. Table 1 summarizes the control methods identified in the research study.

On May 11, 1998, Maryland SHA approved a sound barrier policy promoting a collaborative, coop-

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erative partnership with local governments through a commitment to provide local planning agencies with environmental documents and study reports. In addition, the policy offers an incentive through funding Type II noise abatement projects (see box this page) within an eligible county or other local jurisdiction.

Maryland SHA will not approve funding for a Type II project unless the local jurisdiction has established land use controls or ordinances restricting noise-sensitive development adjacent to state highways. The agency has provided technical assistance to several jurisdictions in establishing regulations to address highway noise in the land use and subdivision approval process.

Two counties have implemented policies and procedures. Another local municipality has initiated development of an ordinance with the assistance of Maryland SHA staff. Currently, five Maryland counties have established land use control regulations or programs, all in the central part of the state between the Baltimore and Washington, D.C., metropolitan areas. The incentive of Type II eligibility has proved most effective.

In recent land use control efforts, Maryland SHA has established minimum setbacks from various roadways, adopted into county regulations. The county agency also developed procedures and guidelines for relaxing the setback distances if a detailed noise impact analysis demonstrates that physical conditions or other site-specific circumstances would reduce or limit the potential noise intrusion into the property.

Other State Strategies

Other states have conducted research studies to support and promote land use planning. One common discovery is that many of the mechanisms, regulations, and laws are already in place (see sidebar, page 33). Success and effectiveness in the planning process often depend on knowledgeable implementation of this guidance.

In cooperation with local government representatives, the Michigan Department of Transportation (DOT) is developing a sample noise ordinance guidebook for municipalities. Michigan DOT policy does not allow consideration of a noise abatement project unless local authorities have compatible land use zoning or building regulations in place to preclude future noise abatement needs. The policy recognizes that local authorities have sole power over land use and zoning and encourages appropriate land use controls to minimize the effects of traffic noise on new development (*4*).

Washington State also links the consideration of noise barriers to a local jurisdiction's agreements or regulations prohibiting or controlling new development adjacent to highways. For many state DOTs, providing technical assistance and reviewing analyses for developers and local jurisdictions is a small price to reduce or eliminate future liabilities for constructing noise barriers.

An Ohio DOT research effort is identifying jurisdictions with a substantial amount of undeveloped land. The second phase will target educational outreach to the jurisdictions, as well as support for planning efforts (see sidebar, page 34).

Local Authority

The Maryland–National Capital Park and Planning Commission, a bicounty agency, has administered an effective program of noise-compatible land use control for more than 75 years. Created in 1927 by the Maryland General Assembly, the agency oversees the development and maintenance of a 52,000-plus acre regional park system and the land use planning for Montgomery and Prince George's counties, two metropolitan counties surrounding Washington, D.C.

Spreading the Word on Noise-Compatible Land Use Planning

MARK FERRONI

The 1998 National Strategic Plan of the Federal Highway Administration (FHWA) contains the goal, "Protect and enhance the natural environment and communities affected by highway transportation." The abatement of highway traffic noise, therefore, is an FHWA priority. Land use controls are a key approach to mitigating highway traffic noise.

FHWA advocates noise-compatible land use planning. In other words, in regulating land development, local governments should prohibit the location of noise-sensitive land uses adjacent to a highway, or should ensure the planning, design, and construction of developments to minimize the noise impacts.

Some state and local governments have enacted legislative statutes for land use planning and control. For example, California legislation on highway noise and compatible land use development requires local governments to consider the adverse environmental effects of noise. The law gives local governments powers to pass ordinances on the use of land, including the location, size, and use of buildings and open space. Other states and local governments have similar laws, but the issue of land use is complicated, and land use control decisions involve an array of competing considerations.

With assistance from Texas Southern University, FHWA conducted workshops on noise-compatible land use this past spring and summer for state and local officials, planners, and developers in Austin, Texas; Phoenix, Arizona; Seattle, Washington; Columbus, Ohio; and Orlando, Florida. The half-day sessions presented noise-compatible land use planning strategies and encouraged a proactive approach to addressing the problems of traffic noise for land use next to highways.

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The creation of the commission was visionary, recognizing the need to plan for orderly development when growth was gaining momentum. The early effort in the management of natural resources minimized or avoided adverse effects from the development of public facilities such as roads, transit lines, and other infrastructure and of private enterprises such as residential housing or commercial and industrial facilities. As the local entity, the commission represents the land use control prong in the classic three-pronged approach to noise control.

Tools for Developers

Much of the early research to support land use planning as a tool for controlling the impact of transportation noise was initiated at the federal level. Since 1978, the consideration of noise has been part of the Maryland–National Capital Park and Planning Commission's master plan process. The regulatory review process since 1979—including zoning, exceptions, and subdivision and site plans—has included noise analysis and recommendations.

In June 1983, the Montgomery County Planning Board developed and published a document to aid developers, planners, and decision makers in con-

TABLE 1 Evaluation of Noise Control Measures: Howard County, Maryland

Techniques	Effectiveness	Situations Where Feasible	Cost	Applicable to County?
Buffer zones	Good–excellent	Undeveloped areas where land values and lot sizes permit	No cost to community if developer provides	Yes
Land use strategies	Good–excellent	Undeveloped areas where demand for compatible land uses is significant	Varies, depending on circumstances	Yes
Barriers	Fair–excellent, depending on height and mass	Developed and undeveloped areas; best alternative for developed areas	Moderate to high, depending on barrier	Yes
Operational control on vehicles	Poor–fair	Developed areas, where alternative routes are available	Insignificant	No
Grade separation	Poor–fair	Developed or undeveloped; best for new construction	High—not feasible for noise reasons alone	No
Acoustical insulation of adjacent buildings	Excellent, for interior; poor, for exterior	Developed or undeveloped; best during building construction	High, especially after construction	Yes
Location, orientation, and structural limitations on adjacent buildings	Good	Undeveloped areas	Low	Yes
Landscaping	Poor	Developed and undeveloped areas	Depends on size of buffer areas	Yes

Source: Howard County Transportation Noise Study, Maryland State Highway Administration Research Report, July 1982.

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Montana Study Guides Noise Abatement Strategies

The state of Montana recently completed a research study of nontraditional noise abatement solutions, identifying four major areas of interest:

- Pavement types and texturing,
- Sound insulation,
- Traffic management techniques, and
- Noise-compatible land use planning and development.

The study found that many mechanisms are already in place at the local level that are conducive to effective land use planning, and that general awareness of the issue was well established. Through surveys of citizens and local planners, the study revealed that much of the state's new development is in nonurban jurisdictions, which have limited resources and less public support than more urbanized areas. Recommendations for the Montana Department of Transportation (DOT) to consider included:

- Support legislation requiring local jurisdictions to address noise issues during the planning process.
- Form a task group to develop a model noise guideline for local agencies and officials.
- Develop sample noise abatement design specifications and standards for use by local government.
- Consider a role in reviewing proposed noise abatement strategies for new developments adjacent to state highways, as part of a technical assistance program.
- Educate local planning officials about the effects of allowing noise-sensitive development next to major highways and about community eligibility for Type II noise abatement.
- Change department policy so that noise abatement would not be required for road-widening projects for communities built after the existing road.

Another survey gauged the opinions of local planners on the issue of noise-compatible land use planning. The survey found that more than three-quarters of planners favor noise-compatible development. The respondents also pointed out that technical assistance from the state and federal governments is needed for the programs to succeed. Necessary resources for local agencies include the following:

- Introductory publications;
- General guidelines for noise-compatible land use planning;
- Model subdivision ordinances and building code addenda for preventing or reducing traffic noise impact;
- Technical training—such as a workshop on noise-compatible development; and
- Technical assistance.

The survey of local planners identified several important roles for Montana DOT in ensuring the success of local noise-compatible development programs:

- Providing sound-level information for undeveloped lands along proposed roadways;
- Facilitating the training of city and county staff and consultants;
- Serving as an information resource or clearinghouse for statewide or national activities in noise-compatible development; and
- Educating developers and the public about eligibility for Type II abatement—specifically that the DOT does not provide noise abatement for communities newly built along existing roadways.

The research study has raised awareness of noise-compatible land use and traffic noise in Montana. Dissemination of the study results will assist in continuing the dialogue and coordinating efforts between Montana DOT and the local planning agencies.

PHOTO: CORA HELM, MONTANA DOT

Home-made berm to block noise from Interstate 90, west of Bozeman, Montana.

PHOTO: CORA HELM, MONTANA DOT

Land adjacent to residential development in Bozeman, Montana, in September 2003, is now built over for commercial use.

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Improving Coordination with Local Planners

Ohio Program Looks at Results

ELVIN W. PINCKNEY

The Ohio Department of Transportation (DOT) is working to improve coordination with officials in local planning agencies across the state to identify potential noise impact zones along highways and to prevent incompatible development. With a proactive approach before the start of environmental studies, Ohio DOT is seeking the best opportunity to contribute to residential zoning and development decisions.

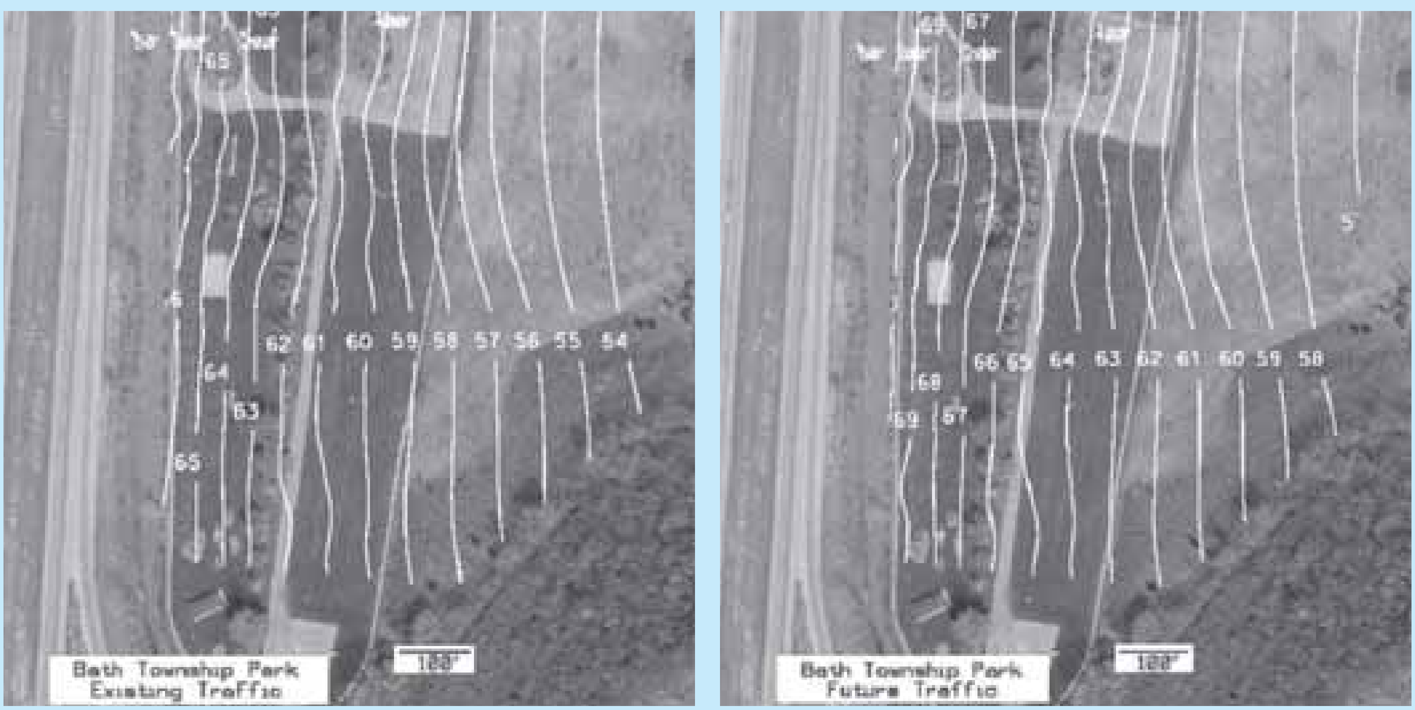
Aerial view of the I-675 corridor near Bath Township, Ohio.

In Phase I, a pilot study is investigating technical aspects, with I-675 in Greene County near Dayton as the study area; researchers are working with the Miami Valley Regional Planning Commission and Greene County. The I-675 corridor is the newest Interstate–urban outerbelt in Ohio, with many adjacent undeveloped areas.

Five open parcels of land along I-675 were selected for study. Two were undeveloped, one was a park, and two were school fields, which permitted easy access for the noise measurements under the FHWA Traffic Noise Model validation process. Traffic sound level contours were developed for the properties now and in 2025.

Phase 2 will educate local jurisdictions about traffic noise and incompatible land use. If local public officials in the study area consider a change in zoning to foster noise-compatible land use, Ohio DOT will extend the program statewide, involving all 17 metropolitan planning organizations. The goal of increased awareness of land use planning with respect to traffic noise is to save millions of taxpayer dollars a year by not having to build noise barriers.

The author is Noise and Air Quality Coordinator, Office of Environmental Services, Ohio Department of Transportation, Columbus.



Traffic sound level contours for properties adjacent to I-675 in Bath Township, (left) now and (right) in 2025.

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sidering the effects of transportation noise and in proposing solutions (5). The board delineated a process for evaluating the impacts of transportation noise; described funding responsibilities; and supplied a comprehensive reference base of techniques, policies, and guidelines. The primary sources were documents developed by the federal and the Maryland state governments.

Funding responsibilities are a complex issue that can be linked to the various stages of the transportation project and the private development. The board's guidance document presents a matrix of situations according to stages of development (see Table 2).

The matrix illustrates the evolution and shift of responsibility for addressing noise and abatement solutions. The earliest planning phase of a private development project presents the greatest potential for effective land use control; the local agency then has the prime responsibility and the greatest influence.

The design phases require shared responsibility and cooperation between the private developer and the agency charged with infrastructure development. When construction is under way, responsibility for noise abatement for facilities or developments that were "there first" falls to the agency responsible for the new facility or project.

TABLE 2 Guidelines for Funding and Construction of Noise Abatement Measures: Montgomery County, Maryland (*5*)

Development Stage	Need and Planning Stage	Design and Engineering Stage	Construction Stage
Planning	- Location in accordance with existing and approved development. (*a,b*)* - Development should be compatible or capable of achieving compatibility. (*b*)* - Additional right-of-way should be requested for noise abatement.	- Compatible land uses strongly encouraged. (*b*)* - Alternative roadway alignments evaluated for noise mitigation potential. (*b,a*)*	- Compatible land use strongly encouraged. (*b*)* - Identify potentially incompatible land uses and suggest solutions. (*b*)*
Design/ Approval	- Compatible land use encouraged. (*b*)* - If noise-incompatible land use proposed, encourage all nonstructural means for noise impact abatement. (*b,c*)*	- Local authority to act as intermediary to state agency and developer to devise cost-effective noise abatement measures. (*b,a,c*)*	- Site layout should be compatible with transportation noise, reducing impact. Developer should consider site layout and structural means of noise abatement. (*b,c*)* - When land not sufficient for berm or barrier, consider use of right-of-way. (*a,d*)*
Constructed	- Decisions about locating roadway should consider protection of pre-existing development, as well as cost-effectiveness and aesthetics. (*a,b*)*	- Evaluate all highway-related noise abatement strategies. (*a*)* - Considerations of cost-effectiveness and aesthetic impact. (*a,b*)*	- Noise abatement project on road may be eligible for federal-aid funding; otherwise, state agency reduces noise impact in reconstruction. (*a*)* - If buildings in noise impacted areas are being reconstructed, encourage acoustic treatment. (*b,e*)*

* Responsible parties:
a Maryland State Highway Administration
b Maryland–National Capital Park and Planning Commission
c Developer
d Montgomery County Department of Transportation
e Homeowners

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Predicting Highway Traffic Noise

JUDITH L. ROCHAT

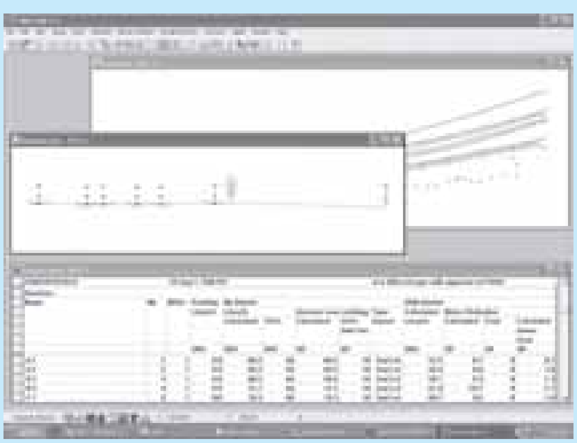
Noise should be considered at all stages of transportation system projects, from original design and construction to modifications. Models for predicting highway traffic noise help to determine which residences and communities would be affected by noise; the models also guide the design of abatement strategies.

The Federal Highway Administration (FHWA) developed the FHWA Traffic Noise Model® (TNM) to help in complying with policies and procedures under U.S. regulations. The TNM is a state-of-the-art computer program for predicting noise impacts in the vicinity of highways and for designing efficient, cost-effective highway noise barriers.

Microphones and sensors measuring traffic noise.

The current model is Version 2.5, now required in all new traffic noise analyses for federal-aid highway projects. The FHWA TNM contains the following components:

- Graphical user interface;
- Vehicle noise emission database with more than 6,000 pass-by events measured at 40 sites across the United States;
- Modeling of five standard vehicle types, including automobiles, medium trucks, heavy trucks, buses, and motorcycles, as well as user-defined vehicles;
- Modeling of both constant-flow and interrupted-flow traffic;
- Sound level computations based on a one-third octave-band database and algorithms;
- An interactive, graphical tool for designing and optimizing noise barriers;
- Models for attenuation over and through rows of buildings and dense vegetation;
- Multiple diffraction analysis;
- Parallel barrier analysis; and
- Contour analysis, including sound level contours, barrier insertion loss contours, and sound-level difference contours.



Screen from FHWA Traffic Noise Model 2.5.

The Volpe National Transportation Systems Center is conducting a long-term study to quantify and assess the model's accuracy and to make recommendations for use. The study involves highway noise data collection and modeling for comparison.

The first phase of the study examined more than 100 hours of traffic noise data collected at 17 sites across the United States and identified opportunities for improvement in the predictions, leading to the development of Version 2.5. The validation study continues and will make additional recommendations for improvements and use.

FHWA also has developed a screening tool for use in simple applications of the model. The look-up tables provide a reference of calculated results for simple highway geometries. The software can be downloaded from the TNM website. In addition, the website contains

- An overview of the FHWA TNM software;
- Information on all versions of the FHWA TNM;
- Announcements about new releases, validation study results, and other important information; and
- Technical support, including an extensive section of frequently asked questions, with a guidelines page and a user's forum.

For more information see www.trafficnoisemodel.org.

The author is a Physical Scientist at the U.S. Department of Transportation, Volpe National Transportation Research Systems Center, Cambridge, Massachusetts.

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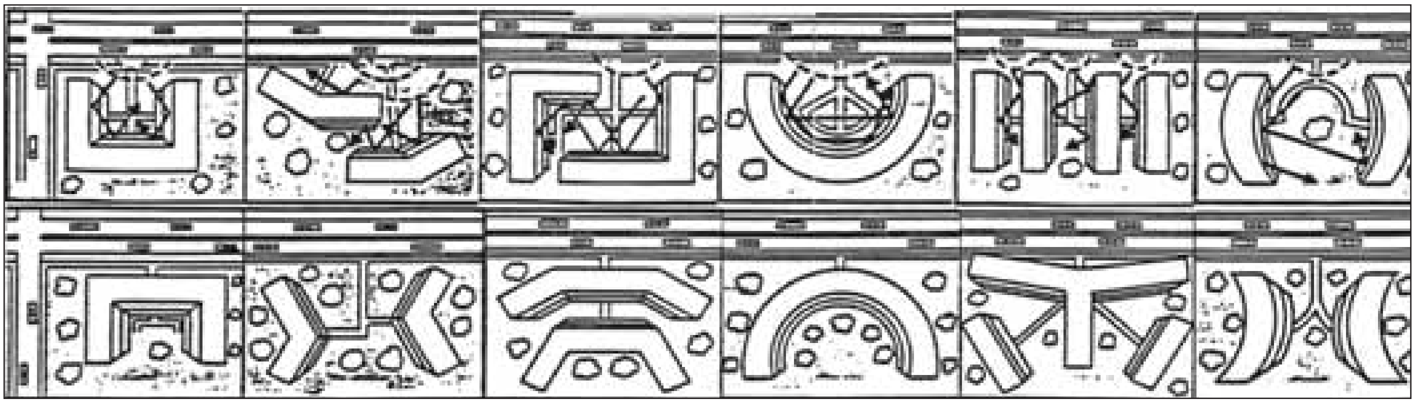

FIGURE 1 Maryland–National Capital Park and Planning Commission guidance on orientation of buildings to minimize noise intrusion or susceptibility to noise impact from highway (top row: poor solutions; bottom row: better solutions).

Developers have implemented noise abatement in response to regulatory requirements, often by grading or adding berms to create a physical barrier between the highway and the proposed development. Walls also have been effective for noise abatement but are expensive. The Maryland–National Capital Park and Planning Commission guidance also promotes noise abatement by site design and building orientation (see Figure 1).

Challenges to Success

A successful land use planning program requires a commitment from all stakeholders. Resources and staff are needed at the local level to provide proper, consistent guidance to the development community.

Pennsylvania State University surveyed planning directors at the local or county level about the most significant barriers to effective planning. Of the 18 barriers identified, foremost was the limited support, understanding, interest, and demand for planning by elected officials. Limited funding for planning was cited almost as frequently and is clearly related. The results indicated that barriers to effective planning were at the people level and not entirely the result of limited financial resources (6).

Another report, in the web-based *Journal of Extension*, examined land use planning challenges in the rural West. Rural settings have different potential growth rates from those of urban and suburban settings, as well as different concerns, such as the presence and preservation of natural amenities. Other common problems in rural settings include fragmented and overlapping authority over development and the typically larger size of planning areas, which leads to less coherent planning visions and a weaker sense of local identity. The conclusion was that success in a rural setting was a direct function of stakeholder engagement or interest (7).

Stakeholder Partnerships

Effective land use planning and the promotion of noise-compatible development require a partnership of all stakeholders. In the support and advocacy roles, the federal and state governments provide the necessary tools—research into effective techniques, resource and reference materials, technical assistance, and the promotion of the broader view of

Regulatory Change Requires Use of Traffic Noise Model

MARK FERRONI

The noise regulations developed by the Federal Highway Administration (FHWA) under the Federal-Aid Highway Act of 1970 apply to highway construction projects that have received federal funding at the request of a state's department of transportation (DOT).[1] A state DOT must determine if there will be traffic noise impacts in areas adjacent to federally aided highways when a project is proposed to

- Construct a highway on a new location, or
- Reconstruct a highway to change the horizontal or vertical alignment or to increase the number of through-traffic lanes.

Analysts must use a highway traffic noise prediction model to calculate traffic noise levels and to determine the traffic noise impacts. As of May 2, 2005, revised regulations specify use of the FHWA Traffic Noise Model (TNM)—or any other model that FHWA has determined is consistent with the TNM methodology.[2]

The latest revisions have removed references in the regulation to a noise measurement report and to vehicle noise emission levels. The revised rule also incorporates corrections to the section on federal participation in a noise mitigation project.

[1] 23 CFR 772.

[2] http://dms.dot.gov/; click on "Simple Search," and enter docket number "18309." Refer to this website or to the Federal Register for updates.

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Sound barrier wall on urban street.

growth and development. This big-picture view shapes the direction and focus of local land use planning programs. Strong support and advocacy increase the success and effectiveness of development that is compatible with the prevailing noise environment.

At the local level, the agencies that administer and enforce the regulations and ordinances governing land use must be committed to effective planning as a way to enhance the community's quality of life. With the proper tools and the technical and financial resources, local jurisdictions can succeed, recognizing the economic and practical implications of the regulatory requirements and decisions. In partnership with the development community, noise-compatible development can be implemented that is economically viable and that provides tangible benefits through an improved quality of life.

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Highway Traffic Noise Course Under Construction

MARK FERRONI

In 2002 the Noise Team of the Federal Highway Administration's (FHWA) Office of Natural and Human Environment formed a technical panel to evaluate the National Highway Institute (NHI) course, Fundamentals and Abatement of Highway Traffic Noise, which for many years had attracted participants with varying levels of expertise. The panel of staff from the Noise Team, FHWA resource centers and division offices, and representatives from three state departments of transportation (DOTs) determined a need for a basic Noise 101 course for practitioners.

With assistance from the University of Tennessee, FHWA and NHI began the development of a course, Highway Traffic Noise, in summer 2004. The two-and-a-half-day introductory course will provide an overview of a highway traffic noise study, along with practical, interactive training in the basic principles of noise analyses. The course will supply a basic understanding of the fundamentals of noise studies, enabling participants to assist more experienced noise analysts in noise studies, to review noise studies more effectively, and to judge the factors and information to make effective decisions from noise studies.

The course includes sections on basic acoustics and terminology, federal policies and procedures, the traffic noise policy and procedures of the participants' state DOT, noise study requirements, noise measurement, basics of traffic noise modeling and impact determination, introduction to the FHWA Traffic Noise Model (TNM), noise barrier acoustical concepts and design in the TNM, construction noise, public involvement, noise study documentation, and mitigation and abatement topics in land use, source control, and project-related noise abatement. Interactive concepts and technological tools—such as the Interactive Sound Information System—will enhance the learning experience.

The course is in development and should be available through NHI in spring 2006. For details, check the NHI website, www.nhi.fhwa.dot.gov.

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SPECIAL FEATURE

Surface Transportation Reauthorization Arrives

What Are the Outcomes and the Prospects for Research?

ANN M. BRACH

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

On August 10, 2005, President George W. Bush signed into law the long-awaited surface transportation reauthorization legislation. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) provides $286 billion in guaranteed spending for highway and transit programs. Among these are research and technology programs, most of which are contained in the research title, Title V.

The accompanying table lists the provisions in Title V, which cover the Federal Highway Administration's (FHWA) research, technology, training, and education programs; the Bureau of Transportation Statistics (BTS); Intelligent Transportation Systems (ITS) research and related activities; and most of the University Transportation Centers (UTC) program. Also included in the table are selected programs from the transit title. The table compares the funding in these programs with the funding for equivalent categories in the previous authorizing legislation, the Transportation Equity Act for the 21st Century (TEA-21).

The comparison uses multiyear totals and annual averages, because TEA-21 authorized 6 years of funding, but SAFETEA-LU authorizes 5 years of funding for continuing programs. Multiyear total funding is shown for the new programs, most of which begin in the second year of the 5-year bill, Fiscal Year (FY) 2006, and continue for 4 years. Some programs are funded for less than 4 years, and several have subcategories or suballocations not shown in the table.[1] A comparison of equivalent categories shows that funding under SAFETEA-LU has increased by 36 percent, which is roughly equivalent to the increase in total funding for highway programs.

PHOTO: REUTERS

President George W. Bush signs the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, August 10, at the Caterpillar–Aurora Facility, Montgomery, Illinois.

Integrating Research and Deployment

In TEA-21, surface transportation research and technology deployment were the categories that generally represented FHWA-administered programs. In SAFETEA-LU these categories are combined to form the Surface Transportation Research, Development, and Deployment (STRDD) program.

Combining research and deployment was a strategy in the Administration's original proposal, to integrate the activities more closely. The strategy is reflected in several program areas—for example, Innovative Bridge Research and Deployment, Innovative Pavement Research and Deployment, and Safety Innovative Deployment.

New Programs and Earmarks

Many new programs are funded through STRDD—for example, a Long-Term Bridge Performance program, fashioned after the Long-Term Pavement Performance (LTPP) program drawing to a close under the current authorization. SAFETEA-LU also authorizes several new cooperative research programs: in environment and planning, in freight, and in hazardous materials. A second strategic highway research program, SHRP II, is funded for 4 years.

(continued on page 42)

[1] Detailed tables of the year-by-year funding for highway and transit research can be found via TRB's home page, www.TRB.org.

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TABLE 1 Multiyear Totals and Annual Averages for Research: TEA-21 and SAFETEA-LU*

	Multiyear Totals			Annual Averages		
Programs from Title V Research	TEA-21 [a]	SAFETEA-LU	Delta	TEA-21	SAFETEA-LU	Delta
STR + TD for TEA-21; STRDD for SAFETEA-LU [b]	**$842,000,000**	**$982,000,000**	**17%**	**$140,333,333**	**$196,400,000**	**40%**
Surface Transportation Research	***592,000,000***					
Long-Term Pavement Performance [c]	60,000,000	50,600,000	-16%	10,000,000	10,120,000	1%
Seismic Research	12,000,000	12,500,000	4%	2,000,000	2,500,000	25%
International Transportation Outreach	3,000,000	1,500,000	-50%	500,000	300,000	-40%
Surface Transportation Environment and Planning Cooperative Research Program	no funds specified	67,500,000				
Exploratory Advanced Research	no funds specified	70,000,000				
Transportation Technology Innovation	22,000,000	26,000,000	18%	3,666,667	5,200,000	42%
Centers for Surface Transportation Excellence		15,000,000				
Long-Term Bridge Performance		31,000,000				
Advanced Travel Forecasting Procedures		10,500,000				
National Cooperative Freight Research		15,000,000				
Future Strategic Highway Research Program		205,000,000				
Transportation Safety Information Management System		2,000,000				
Surface Transportation Congestion Relief Solutions		36,000,000				
Commercial Remote Sensing Products and Spatial Information Technologies		31,000,000				
Motor Carrier Efficiency Study		5,000,000				
Center for Transportation Advancement and Regional Development		2,500,000				
Hazardous Materials Research Projects		5,000,000				
Biobased Transportation Research		50,000,000				
Motorcycle Crash Causation		2,816,000				
Research Grants		76,500,000				
Technology Deployment	**$250,000,000**					
Innovative Bridge Research and Deployment [d]	108,000,000	65,500,000	-39%	18,000,000	13,100,000	-27%
High-Performance Concrete Bridge		16,500,000				
Innovative Pavement Research and Deployment Program		90,500,000				
Demonstration of Ultra-High-Performance Concrete with Ductility		2,500,000				
High-Performance Steel Bridge		16,400,000				
Steel Bridge Testing		5,000,000				
Safety Innovative Deployment		51,000,000				
Demonstration Projects and Studies		13,300,000				

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	Multiyear Totals			Annual Averages		
Programs from Title V Research	TEA-21 [a]	SAFETEA-LU	Delta	TEA-21	SAFETEA-LU	Delta
Training and Education	**$102,000,000**	**$133,500,000**	**31%**	**$17,000,000**	**$26,700,000**	**57%**
National Highway Institute	39,000,000	48,000,000	23%	6,500,000	9,600,000	48%
Local Technical Assistance Program	51,000,000	55,500,000	9%	8,500,000	11,100,000	31%
Eisenhower Fellowships	12,000,000	11,000,000	-8%	2,000,000	2,200,000	10%
Garrett Morgan Program		5,000,000				
Freight Planning Capacity Building		3,500,000				
Surface Transportation Congestion Relief Assistance and Training		3,000,000				
Transportation Education Development		7,500,000				
Bureau of Transportation Statistics	**$186,000,000**	**$135,000,000**	**-27%**	**$31,000,000**	**$27,000,000**	**-13%**
Ferry Database		2,000,000				
Intelligent Transportation Systems (ITS) Standards, Research, Testing, and Development	**$603,200,000**	**$550,000,000**	**-9%**	**$100,533,333**	**$110,000,000**	**9%**
Commercial Vehicle ITS Infrastructure [e]	184,100,000	[100,000,000]				
Multistate Corridor Operations and Management		35,000,000				
Rural Interstate Corridor Communications Study		3,000,000				
Road Weather Research and Development		20,000,000				
ITS Deployment [f]	**$679,000,000**	**$122,000,000**				
University Transportation Research	**$158,800,000**	**$348,500,000**	**119%**	**$26,466,667**	**$69,700,000**	**163%**
Totals, Research Title Only [f]	**$1,892,000,000**	**$2,149,000,000**	**14%**	**$315,333,333**	**$429,800,000**	**36%**
Programs from Title III Public Transportation						
Transit (FTA)						
Transit Cooperative Research Program	45,250,000	46,084,000	2%	7,541,667	9,216,800	22%
National Transit Institute	23,000,000	18,192,000	-21%	3,833,333	3,638,400	-5%
University Transportation Centers (UTC): Transit Portion	36,000,000	33,952,000	-6%	6,000,000	6,790,400	13%
Total UTC Funding (Highway + Transit)	**194,800,000**	**382,452,000**	**96%**	**32,466,667**	**76,490,400**	**136%**

* 6-year totals for TEA-21; 5-year totals for SAFETEA-LU.

[a] TEA-21 funding amounts do not reflect obligation limits. Programs that did not receive contract authority are not included.

[b] STR = Surface Transportation Research; TD = Technology Deployment; STRDD = Surface Transportation Research, Development, and Deployment. In TEA-21, STR and TD were separate programs; SAFETEA-LU combines the programs as STRDD. Funding for STR plus TD is shown in the top row for comparison with STRDD.

[c] Indentation indicates suballocation of funds.

[d] Funding for the Innovative Bridge Research and Deployment Program in SAFETEA-LU is compared with the sum of funding amounts for the Research and Construction components of the Innovative Bridge Program in TEA-21.

[e] Commercial Vehicle ITS funding is provided in the Motor Carrier Safety title of SAFETEA-LU (Title IV), not in the research title; funding for this program is shown for comparison with TEA-21.

[f] ITS Deployment was moved out of the research title in SAFETEA-LU, except in FY 2005. ITS Deployment is not included in the totals for TEA-21 or SAFETEA-LU.

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Reauthorization Arrives

(continued from page 39)

The STRDD program includes a nearly threefold increase in projects earmarked for particular research institutions or for programs to be administered outside of FHWA through the National Academy of Sciences. Four program areas listed in the table—Biobased Transportation Research, Research Grants, Demonstration Projects and Studies, and Transportation Technology Innovation—are collections of earmarks, predominantly to universities, but also to one federal laboratory and several private institutions.

Training and Education and BTS

The Training and Education category covers traditional programs, such as the National Highway Institute (NHI), the Local Technical Assistance Program (LTAP), and the Eisenhower Fellowships for students studying transportation. Each of these programs receives some increase in annual funding—the NHI increase is nearly 50 percent.

Several new training and education programs also are authorized, but with modest annual funding: the Garrett A. Morgan program to encourage women and minority students to enter transportation, a freight capacity building program, a training component for the congestion relief research program authorized under STRDD, and the Transportation Education Development pilot program to develop transportation curricula.

Annual program funding for the Bureau of Transportation Statistics (BTS) falls by 13 percent from the levels in TEA-21. The future of the National Transportation Library had been uncertain for the past 2 years, but the library has been reauthorized. BTS is required to fund a ferry database authorized in Title I of SAFETEA-LU.

ITS and UTC Programs

The ITS Standards, Research, Testing, and Development category receives a modest increase of 9 percent in annual average funding compared with TEA-21 levels. A new program of road weather research is authorized, as well as a program of grants to states in the Interstate 95 corridor. The Commercial Vehicle ITS Infrastructure program is authorized, with funding provided in the Motor Carrier Safety title, not in the research title.

ITS Deployment has been phased out as a distinct funding category. SAFETEA-LU, however, includes funds for ITS Deployment in FY 2005 that already were allocated in the transportation appropriations act.

The UTC program receives the greatest increases in funding over TEA-21 levels. The research title provides most of the program's funding from the highway account of the Highway Trust Fund. A smaller amount is provided in the transit title, mostly from the general fund of the U.S. Treasury. The table combines both sources of UTC funding to show an average annual increase of 136 percent over TEA-21 levels.

The UTC program is divided into four categories of centers: national, regional, Tier 1, and Tier 2. A total of 62 centers receive earmarks, some only for the first or second year of the authorization period, others for most or all of the period. Starting with FY 2007, 20 centers are open for competition. In total, 75 percent of the funding already is earmarked for centers.

Transit Programs

The Transit Cooperative Research Program receives a slightly more than 20 percent increase in annual average funding over TEA-21. The National Transit Institute experiences a small decrease.

These programs are part of a larger transit research and technology program not shown in the table. The larger program receives average annual funding of almost $62 million, from which approximately 25 specific programs or projects are funded; 40 percent of the funds is earmarked for particular recipients.

Title IV of SAFETEA-LU authorizes motor carrier research and development, but no funding is specified.

Opportunities and Challenges

SAFETEA-LU provides many opportunities to advance knowledge and innovation in surface transportation. New programs in diverse areas—such as hazardous materials, weather effects on roads, and biobased transportation—will expand traditional definitions of surface transportation research.

At the same time, SAFETEA-LU poses challenges to the transportation research community. The funding amounts presented here are theoretical maximums—that is, the actual funding will be subject to obligation ceilings and to possible cutbacks because the sum of all the designations under STRDD exceeds the funds provided in some years.

SAFETEA-LU calls for coordination and strategic planning for research, which will involve the cooperation of an array of research funding recipients, inside and outside the federal government, under the leadership of the U.S. Department of Transportation. SAFETEA-LU also calls for outcome-based performance evaluation of federally funded research—a goal that has challenged researchers in all fields.

Research and technology have gained an unusually high profile in the reauthorization process. Accountability and quality in carrying out SAFETEA-LU's investment in research will be critical to the success of research and innovation in the next reauthorization—which is not that far away.

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CALENDAR

TRB Meetings

2005

October

31– Nov. 1 1st National Conference on Roadway Pavement Preservation
Kansas City, Missouri

November

1–3 6th National Conference on Transportation Asset Management: Making Asset Management Work in Your Organization*
Kansas City, Missouri

14–16 2005 International Truck and Bus Safety and Security Symposium*
Alexandria, Virginia
Richard Pain

December

8–9 Data Requirements in Transportation Reauthorization Legislation Conference
Washington, D.C.
Thomas Palmerlee

2006

January

22–26 TRB 85th Annual Meeting
Washington, D.C.
Linda Karson

March

28–30 Transportation and Economic Development 2006*
Little Rock, Arkansas

April

9–11 10th National Light Rail Transit Conference: Light Rail—A World of Applications and Opportunities*
St. Louis, Missouri
Peter Shaw

18–20 Harbor Safety Conference*
Washington, D.C.
Joedy Cambridge

19–21 Visualization in the Changing Transportation World
Denver, Colorado
Richard Pain

June

4–7 North American Travel Monitoring Exposition and Conference
Minneapolis, Minnesota
Thomas Palmerlee

July

TBD Freight Demand Modeling: Improving Analysis and Forecasting Tools for Public-Sector Decision Making
Elaine King

TBD TRB Joint Summer Meeting
San Diego, California
Mark Norman

16–19 3rd International Conference on Bridge Maintenance, Safety, and Management*
Porto, Portugal

16–20 11th AASHTO–TRB Maintenance Management Conference*
Charleston, South Carolina

23–26 45th Annual Workshop on Transportation Law
Chicago, Illinois
James McDaniel

25–29 5th International Symposium on Highway Capacity*
Yokohama, Japan
Richard Cunard

August

6–9 1st International Conference on Fatigue and Fracture in the Infrastructure: Bridges and Structures of the 21st Century*
Philadelphia, Pennsylvania
Stephen Maher

23–26 7th International Conference on Short and Medium Span Bridges*
Montreal, Quebec, Canada
Stephen Maher

October

2–5 Plastic Pipes XIII Conference*
Washington, D.C.

22–25 17th National Rural Public and Intercity Bus Transportation Conference
Stevenson, Washington
Peter Shaw

2007

January

21–25 TRB 86th Annual Meeting
Washington, D.C.
Linda Karson

June

24–27 9th International Conference on Low-Volume Roads
Austin, Texas

Additional information on TRB meetings, including calls for abstracts, meeting registration, and hotel reservations, is available at www.TRB.org/calendar. To reach the TRB staff contacts, telephone 202-334-2934, fax 202-334-2003, or e-mail lkarson@nas.edu. Meetings listed without a TRB staff contact have direct links from the TRB calendar web page.

*TRB is cosponsor of the meeting.

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John William Schumann

LTK Engineering Services

John Schumann grew up in New Jersey riding trolleys, commuter trains, and the New York subway. During family vacations, he and his father visited nearby cities—Boston, Philadelphia, and Cleveland—that had retained trolley lines. Most continue to operate, rebuilt to modern light rail transit (LRT) standards. At an early age, Schumann saw that it would make sense to create trolley lines in other cities to supplement all-bus systems, avoiding some of the larger costs of full rapid transit networks. He had not yet realized, however, that he would have a career helping cities plan and build such projects.

When Schumann earned an undergraduate degree in business administration from Ottawa University, Ottawa, Kansas, in 1964, the rail industry was nearing its lowest point, lacking job opportunities. He set aside his passion for railroads and transit and accepted a position as a credit analyst for an oil company in suburban Pennsylvania. Six years later, Schumann accepted an opportunity to enroll in Drexel University's graduate transportation program. Mentored by his adviser, Dr. Thomas N. Harvey, Schumann earned a master's degree in civil engineering with a concentration in transportation.

"We cannot build our way out of congestion by adding more and more roads. Nonroad alternatives are needed to slice the tops off highway traffic peaks."

For the following 7 years, Schumann worked for Louis T. Klauder and Associates (LTK), a Philadelphia engineering consulting firm with a growing rail transit practice. He managed feasibility and economic study assignments, such as assessing commuter rail operating costs and mainline railroad capacity, monitoring Amtrak's Metroliner program, and inspecting Penn Central Railroad lines that were not included in Conrail. During this period, the LRT concept was emerging in North America, allowing Schumann the opportunity to become involved and contribute to the preliminary engineering of Eastside MAX, the first LRT line in Portland, Oregon.

Schumann's introduction to TRB came in 1975, at the first National Conference on Light Rail Transit, held in Philadelphia—a turning point for LRT and for Schumann. He has attended every LRT conference since and has presented papers at most. His regular updates, *Status of North American Light Rail Transit Systems*, have become an opening feature at TRB LRT conferences. He has been a member of TRB's LRT subcommittee since 1989 and he chaired the committee from 2000 to 2004.

"TRB played a pivotal role in bringing modern LRT to North America," says Schumann, "not by advocacy, but by carefully evaluating systems operating throughout the world and considering how such technology might be usefully applied to build better public transit systems here."

In 1979, Schumann began working as a senior planner for the Sacramento Regional Transit District, in California, leading studies that determined the feasibility of LRT in the city's northeast and Folsom corridors. He managed the planning, design, and construction of Sacramento's 18-mile LRT starter line, which Schumann refers to as his "lifetime personal best project." The starter line cost less than any other federally funded new rail project in U.S. history. Today, LRT provides the backbone of transit in Sacramento, coordinated with buses to form a multimodal, multidestinational transit network.

Schumann rejoined LTK in 1985, in the Portland, Oregon, office. He has contributed to rail transit, commuter rail, and intercity rail projects in more than 30 cities around the United States, as well as in England, Chile, and Dubai. His projects included outlining an intercity service plan for Portland, similar to the plan later implemented by the states of Washington and Oregon; contributing to state passenger rail plans for Arizona and South Carolina; and helping to develop streetcar plans for several cities, including Atlanta, Miami, Oakland, Portland, and Winston-Salem.

After traveling all over the world, Schumann was most impressed by the Swiss public transportation system, which consists of conventional railroad, light rail, and bus operations meticulously maintained and continually improved over many decades. The public and private operators work together to provide frequent service, with time-coordinated connections between lines at major stations, so that the country is on one large interconnected timed-transfer network that is very easy and convenient for everyone to use.

"With only a little more effort, expense, and commitment to practicality, subareas of the United States, urban and super-urban, could achieve the same kind of system and similar results," says Schumann. "Our tendency to distrust and underfund public enterprises—such as urban rail systems—prevents our public agencies from achieving the results we want. People in the United States are realizing that we cannot build our way out of congestion by adding more and more roads, and that nonroad alternatives are needed to slice the tops off highway traffic peaks."

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PROFILES

Dean L. Sicking

Midwest Roadside Safety Facility
University of Nebraska, Lincoln

For 25 years, Dean L. Sicking has been making U.S. highways safer for drivers. It is nearly impossible to drive on a highway in this nation without encountering safety features that Sicking developed, including guardrails, bridge rails, median barriers, sign and mailbox supports, crash cushions, and drainage features. These designs have prevented hundreds of fatalities and injuries and have improved the safety of motorists across the nation.

Director of the Midwest Roadside Safety Facility since 1992, and the Leonard A. Lovell Professor of civil engineering at the University of Nebraska, Lincoln (UNL), Sicking cites as his most significant contribution to improving roadside safety the development of guardrail extruder terminals, the ET-2000. The terminal was the first energy-absorbing guardrail terminal system created for the W-beam guardrail—the most widely used guardrail in the United States. The design enables the guardrail to dissipate the energy from an impact and to decelerate the vehicle safely.

"An engineer who encounters a substandard system or design that endangers the public is obligated to alert the client and to work tirelessly to eliminate the problem."

The ET-2000 is credited with preventing an estimated 150 fatal crashes annually that would have occurred with older-style terminals. The Federal Highway Administration presented its 1992 Safety Award to the Texas State Department of Transportation, which funded the development of the ET-2000.

Sicking earned a bachelor's degree in mechanical engineering, a master's degree in civil engineering, and a Ph.D. in civil engineering from Texas A&M University, College Station. After completing his education, in 1980, he worked for the Texas Transportation Institute (TTI) for 12 years as an engineering research associate, assistant research engineer, and finally an associate research engineer. At TTI, he developed many roadside safety devices, such as permanent and temporary longitudinal barriers, crash cushions, safety treatments for roadside drainage structures, and breakaway support systems.

"Research is the only weapon that highway agencies have in the battle to control the cost associated with the public's demand for higher levels of service on the National Highway System," says Sicking. "Transportation agencies would benefit greatly if this tool was used more aggressively."

Although Sicking has spent the majority of his career on roadside safety, the project that has garnered the most attention began in the fall of 1998—the development of the Steel and Foam Energy Reduction (SAFER) barrier. Supported by the Indy Racing League and NASCAR, Sicking led the effort to create an energy-absorbing barrier for high-speed race tracks, to reduce the risk of injury from collisions.

Almost a year into Sicking's efforts, legendary race car driver Dale Earnhardt was killed in a collision at the Daytona 500. Sicking was part of the team that investigated the collision, including the critical angle at which the vehicle hit the wall, the seat belt breaking during the crash, and the contact from another car, which had moved Earnhardt out of position in his vehicle. The information gathered from the investigation contributed to Sicking's development of the SAFER barrier.

The SAFER barrier absorbs energy during a crash by spreading the impact of a car over a longer period of time and distance, improving the driver's chances of survival. In more than 30 high-speed collisions since the SAFER barrier was installed at the Indianapolis Motor Speedway, no serious injuries have been reported.

Sicking's group from the University of Nebraska–Lincoln has won more than 10 awards for the SAFER barrier, including the Louis Schwitzer Award, the Specialty Equipment Market Association Motorsports Engineering Award, the Herb Porter Award, and the Best of What's New Award from Popular Science.

Associated with TRB since 1992, Sicking served as a member on the Motor Vehicle Tehnology committee and the Roadside Safety Design committee. He was active on both the NCHRP Project Panel on Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features and the NCHRP Project Panel on Recovery Area Distance Relationships for Highway Roadsides. Presently, he chairs the Roadside Safety Design Committee.

As a professor, Sicking seeks not only to train students to become good engineers, but to encourage positive attitudes in their lives and work. "Many temptations will arise to cut corners and relax standards to win a contract or complete a job under budget," he explains. "Engineers must resist these temptations, or eventually someone will die. An engineer who encounters a substandard system or design that endangers the public is obligated to alert the client and to work tirelessly to eliminate the problem."

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NEWS BRIEFS

PHOTO: CALIFORNIA DEPARTMENT OF TRANSPORTATION

Changeable message sign assists Los Angeles-area motorists in making route choices.

Caltrans Project Posts Commuter Travel Times

In August, the California Department of Transportation (Caltrans) in Los Angeles began testing out a system that uses 14 changeable message signs in 7 highway corridors to inform motorists of the estimated time to drive through traffic to local destinations. The goal is to ease tension among commuters by providing information related to their commute.

The system taps into data available from Caltrans sensors placed every one-third to one-half mile in each highway lane—to measure traffic speed, transmitting information on traffic flow every 30 seconds. Each changeable message sign displays the estimated travel time to two destinations calculated from the sensor data.

Frank Quon, Deputy District Director of Operations in District 7 of Caltrans, explains that commuters are helping to manage the transportation system by choosing their routes, "the more information motorists have, the more informed choices they will make."

Caltrans posted an online survey for commuters to give their feedback to the system. Responses have been positive—commuters have found the system easy to understand and most respondents have been pleased with the accuracy of the times listed on the message signs, stating that the times met or exceeded their expectations. According to Quon, 9 percent of motorists reported that they had changed their routes because of the posted travel times.

If the test period proves successful, the system will expand to 120 freeway signs in the Los Angeles region. By the end of the year, Quon notes that Caltrans plans to have a website to post travel times, traffic advisory messages, incident reports, closures, travel speeds, road conditions, and closed-circuit television images, so that people are able to plan, estimate their trip time, and choose alternative routes.

For more information contact Jeanne Bonfilio at Caltrans (213) 897-3630, Jeanne_bonfilio@dot.ca.gov.

Highway Bypass Planned Near Hoover Dam

A project team led by the Central Federal Lands (CFL) office of the Federal Highway Administration and consisting of five other government agencies is developing a highway bypass to U.S. 93 over Hoover Dam in Nevada. The dam is a major tourist destination, overloading the highway with a mix of tourist traffic and heavy commercial trucks, increasing hazards for drivers and the security burden for the Bureau of Reclamation, which operates the dam.

The plan is to construct a steel and concrete arch about 1,500 feet downstream of Hoover Dam, spanning the Black Canyon between Arizona and Nevada. The 1,060-foot structure will be the longest concrete arch in North America and fourth longest in the world and will allow through-traffic on U.S. 93 to bypass Hoover Dam.

CFL chose the plan for the new bridge after studying four alternative plans, including a no-build option, and after receiving comments from the public and from other local, state, and federal agencies. The bypass construction plan also minimizes environmental impacts; offers engineering and operational advantages; minimizes harm to historic preservation properties; and costs slightly less than the other construction proposals.

A website dedicated to the project (www.hooverdambypass.org) contains live images of the construction process, renderings of the completed project, and an animated sequence portraying the project before and after completion.

For more information, go to http://www.hooverdambypass.org/default.htm.

PHOTO: HOOVERDAMBYPASS.ORG

A computer–generated visualization of the composite deck arch bridge under construction as an alternative traffic route to bypass Hoover Dam.

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TRB HIGHLIGHTS

Committee Outreach

Linking Up with Transportation History Museums

BY LAUREL RADOW AND KATHRYN HARRINGTON-HUGHES

With a mission to establish and promote the importance of maintaining a sense of history and preserving historical archives among transportation professionals, the TRB Transportation History Committee has compiled a list of links to websites that provide information on transportation history museums and resources in the United States. The list is available on the committee's website, http://gulliver.trb.org/committees/ABG50.pdf.

The links are categorized into 10 topic areas: automobile, maritime, aviation, motorcycle, bicycle, railroad, bus, transportation, highway, and trolley. For a comprehensive directory of transportation museums, libraries, and archives, the committee recommends MuseumStuff.com (www.museumstuff.com/museums/types/transportation/all.html), which offers an alphabetical list of more than 160 museums, libraries, and archives, with brief overviews and website links. Museums with an emphasis on canals are omitted from the comprehensive list but can be found with a keyword search.

The International Council of Museums (ICOM) is another timely source of information on transportation museums (http://icom. museum/vlmp). The International Association of Transport and Communications Museums—one of the 15 specialist international organizations affiliated with ICOM—also hosts a directory of museums (http://www.iatm.org/finished/ start_klein.php).

In addition, the online encyclopedia Wikipedia publishes a list of transportation museums throughout the world (http://en.wikipedia.org/wiki/ List_of_transport_museums), noting, "Old transportation systems don't disappear, they often become the park and recreational facilities of future generations. Parts of many dismantled trolley systems in the United States, for instance, have become trolley museums."

Transportation History Committee Chair Alan Pisarski predicts a surge of interest in transportation's past: "Next year marks the 50th anniversary of the Federal-Aid Highway Act, signed into law by President Dwight D. Eisenhower on June 29, 1956. Celebrations of this event, which called for uniform Interstate design standards to accommodate a 20-year traffic forecast, are likely to increase interest in the history of the U.S. transportation system and to encourage transportation museums to examine the role of the National System of Interstate and Defense Highways in the nation's economy, culture, and defense."

PHOTO: CHESAPEAKE BAY MARITIME MUSEUM

Hooper Strait Lighthouse, saved from demolition in the 1960s, is one of more than 10 exhibit buildings on the waterfront campus of the Chesapeake Bay Maritime Museum, St. Michaels, Maryland.

The Transportation History Committee website will post museums' plans to highlight the role and history of the Interstate System.

Radow is with the Office of Transportation Operations, Federal Highway Administration, Washington, D.C. Harrington-Hughes is Director, Corporate and Foundation Relations, Chesapeake Bay Maritime Museum, St. Michaels, Maryland.

PLANNING IT SAFE—The Transportation Safety Planning Working Group convened July 21, in Washington, D.C., to discuss strategies for training, conference presentations, and communications materials for educating elected officials. Action items include conducting a workshop on safety planning tools, developing guidance for transportation planners, assisting federal agencies with reauthorization rollout, and developing communications resources. (*Photo, left to right:*) Michael Trentacoste of the Federal Highway Administration (FHWA); Rob Ritter, FHWA; and Charles Goodman, Federal Transit Administration.

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Multicommittee Program

Controlling Invasive Species: Strategies and Techniques

BY CARLOS BRACERAS

The transportation corridors that cross private and public lands—not only highways but also waterways, rail right-of-ways, and airways—can assist in the unwanted and invasive spread of problematic, nonindigenous animal and plant species. According to presentations at a 2005 TRB Annual Meeting workshop, the issue is complex, and state departments of transportation (DOTs) must play a role in solving an environmentally and economically costly national and international problem.

Nine TRB committees jointly developed the workshop program to review information about invasive species, to present solutions for invasive species management, and to address opportunities to work together on invasive species issues. The session brought together transportation professionals from a range of disciplines to consider three sets of presentations moderated by Arnold Konheim, Senior Policy Analyst, U.S. DOT; Lynne Irwin, Cornell Local Roads Program; and Gordon Brown, Invasive Species Coordinator, U.S. Department of the Interior.

The first set of presentations reviewed the background, including the history of invasive species pathways, the environmental and economic costs, national and international efforts at controls, and a summary of what is being done and what needs to be done.

The second group of presentations focused on measures to control and prevent the spread of various invasive species. Among the primary countermeasures are the use of electronic database systems to identify and categorize the species that pose the most serious problems; working with the public to increase awareness and to form partnerships to establish controls; developing regulations and technology for the maritime industry to prevent the introduction of invasive species via ballast water; and planning the movement of military equipment to reduce the risk of transporting invasive species.

Opportunities to address the spread of invasive species include management of ballast water, conservation in transportation, and state DOT efforts to develop and apply practical solutions. The workshop presented a case study of a program to prevent the spread of invasive plants and to stimulate restoration in Adirondack Park in New York State.

Following up on the workshop, the Roadside Maintenance Committee is working on a program to explore the ecology of weeds, partnerships for weed control, and restoration after the removal of weeds. The Environmental Maintenance Subcommittee of the Maintenance and Operations Management Committee has continued discussions on the control of invasive plants.

The workshop presentations are available online on a web page assembled by the Transportation Needs for National Parks and Public Lands Task Force: http://refugedata.fws.gov/trb/ 2005Workshop/index.html.

The author, who presided at the workshop, is Deputy Director and Chief Engineer, Utah DOT, and Chair of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Maintenance.

INFORMATION, PLEASE— The Transportation Information Management Committee held its concluding session on August 19, in Washington, D.C., to consider results from a study on sustainable administrative structures and funding mechanisms for meeting the information services needs of the transportation sector. The committee developed findings and recommendations to define core services, identify how to provide the services, and suggest options for funding. (*Left to right*:) Leni M. Oman, Washington State Department of Transportation; R. David Lankes, Syracuse University; Nina L. McLawhorn, Wisconsin Department of Transportation; and Michael D. Meyer, Georgia Institute of Technology.

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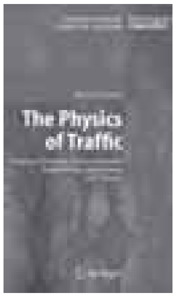


The Physics of Traffic: Empirical Freeway Pattern Features, Engineering Applications, and Theory
Boris Kerner. Springer, New York, 2004; 682 pp.; $139; 3-540-20716-3.
Traffic congestion, a part of everyday life for most drivers, is analyzed and explained in this book. Boris Kerner, who has published several papers on traffic flow in the *Transportation Research Record: Journal of the Transportation Research Board*, presents a theory that combines recent insights into empirical data with mathematical models for freeway traffic. The first part reviews the history of traffic theories, including the three-phase traffic theory—the basis for a physical theory of traffic phenomena with applications to engineering. The second part examines empirical spatiotemporal patterns, including pattern evolution at traffic bottlenecks and pattern formation caused by peculiarities of freeway infrastructure. Finally, the third and fourth parts address the mathematical model and engineering applications.

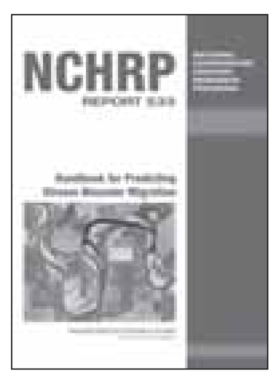
Container Transport Security Across Modes
European Conference of Ministers of Transport. Organisation for Economic Co-Operation and Development, Paris, France, 2005; 125 pp; $38; 92-821-0331-5.
The security of maritime shipping containers is a major concern for authorities. Initiatives to enhance security in container transportation generally focus on individual modes; however, the transfer between modes along the container transport chain may create vulnerabilities. This compilation of information from governments, industry, and international organizations focuses on terrorism targeting maritime container transport. The complex hybrid container transport system is described, along with the variety of parties involved in the system. Points of security weakness are identified, and recommendations are made for improving the system.

Progress in Activity-Based Analysis
Edited by Harry Timmermans, member of TRB Travel Survey Methods Committee, the Moving Activity-Based Approaches to Practice Task Force, and other committees. Elsevier Science, Ltd., Netherlands, 2005; 528 pp.; $120; 0-08-044581-0.
To capture the complexity of travel behavior, researchers have gradually shifted from trip-based, to tour-based, to activity-based models. This volume contains reflections on the development and application of activity-based models in the past decade. The three sections review approaches for incorporating complexity to models; discuss how to obtain the data necessary to support complex models; and report on applications.

Best Endeavours: Inside the World of Marine Salvage
Tony Redding. ABR Company Limited, United Kingdom, 2004; 256 pp.; £27.50; 1-904050-09-3.
Published at the 50th anniversary of the International Salvage Union, this book analyzes and portrays the challenging business of marine salvage, with accounts from more than 100 salvage operations. The determination that makes salvage possible is explored, including desperate struggles to save ships thought to be beyond saving and cases involving work at remote locations under extreme conditions. The author examines the effect of luck in salvage situations and explains how ingenuity and lateral thinking have brought many crippled ships and cargoes to safety. The text is supported with more than 150 photographs depicting the hazards faced by workers in the marine salvage industry.

The books in this section are not TRB publications. To order, contact the publisher listed.

TRB PUBLICATIONS



Handbook for Predicting Stream Meander Migration
NCHRP Report 533
A practical methodology for predicting the rate and extent of channel migration in proximity to transportation facilities is explained. An accompanying CD-ROM contains an ArcView-based data logger and channel migration predictor.

2004; 97 pp.; TRB affiliates, $24; TRB nonaffiliates, $32. Subscriber categories: highway and facility design (IIA); bridges, other structures, and hydraulics and hydrology (IIC), soils, geology, and foundation (IIIA); materials and construction (IIIB).

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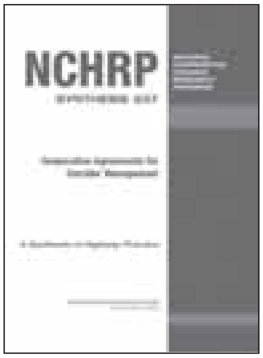

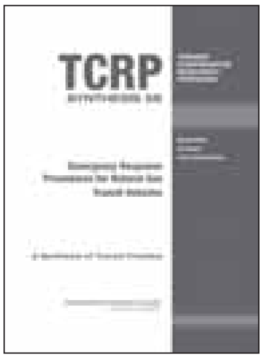

TRB PUBLICATIONS *(continued)*

Guidelines for Inspection and Strength Evaluation of Suspension Bridge Parallel-Wire Cables
NCHRP Report 534
Recommendations are presented for the inspection and strength evaluation of suspension bridge parallel-wire cables. The accompanying CD offers a detailed account of the research leading to the development of the recommended guidelines.

2004; 263 pp.; TRB affiliates, $22.50; TRB nonaffiliates, $30. Subscriber category: bridges, other structures, and hydraulics and hydrology (IIC).

Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide
NCHRP Report 535
A methodology is recommended for the prediction of the long- and short-term mobile source emissions impacts of projects to improve traffic flow. A user's guide and case studies testing the methodology are included.

2005; 227 pp.; TRB affiliates, $21; TRB nonaffiliates, $28. Subscriber categories: planning and administration (IA); energy and environment (IB); highway and facility design (IIA).

Cooperative Agreements for Corridor Management
NCHRP Synthesis 337
The state of the practice in developing and implementing cooperative agreements for corridor management, the elements of such agreements, and successful practices or lessons learned are examined. The focus is on cooperative agreements between two or more government agencies or between public and private entities that address land use and transportation.

2004; 70 pp.; TRB affiliates, $12; nonaffiliates, $16. Subscriber categories: planning and administration (IA); safety and human performance (IVB).

Thin and Ultra-Thin Whitetopping
NCHRP Synthesis 338
This summary of information on the highway community's use of thin and ultra-thin whitetopping overlays as a pavement rehabilitation alternative is designed as a quick reference and a training aid for the practitioner.

2004; 87 pp.; TRB affiliates, $13.50; nonaffiliates, $18. Subscriber categories: pavement design, management, and performance (IIB); materials and construction (IIIB); maintenance (IIIC).

Centerline Rumble Strips
NCHRP Synthesis 339
This synthesis summarizes state-of-the-practice information on the use and design of centerline rumble strips (CLRS), including design, installation, configuration, dimensions, and visibility. Data on crashes before and after CLRS installation are supplied to document safety. The text also explores the availability of policies, guidelines, warrants, and costs for the use and design of CLRS.

2005; 63 pp.; TRB affiliates, $12; TRB nonaffiliates, $16. Subscriber categories: highway and facility design (IIA); pavement design, management, and performance (IIB); highway operations, capacity, and traffic control (IVA); safety and human performance (IVB).

Convertible Roadways and Lanes
NCHRP Synthesis 340
The historical development of reversible lanes is documented, focusing on a variety of applications, lessons learned from implementation, and the costs and benefits. The techniques and practices developed to execute reversible operations more effectively are explained.

2004; 92 pp.; TRB affiliates, $13.50; nonaffiliates, $18. Subscriber categories: highway operations, capacity, and traffic control (IVA); safety and human performance (IVB).

Emergency Response Procedures for Natural Gas Transit Vehicles
TCRP Synthesis 58
This volume offers insight into current emergency response practices for natural gas incidents involving transit vehicles. Practices were determined through agency surveys and an examination of procedures provided by several transit agencies. The synthesis is intended for transit and transportation professionals addressing safety concerns and preparing first responders for natural gas incidents.

2005; 53 pp.; TRB affiliates, $11.25; TRB nonaffiliates, $15. Subscriber category: public transit (VI).

Strategic Planning and Management in Transit Agencies
TCRP Synthesis 59
Some form of strategic planning and management is being implemented by more than 80 percent of the transit agencies that were randomly sampled for this synthesis. Both internal and external benefits are identified. Internal benefits include helping to create a new organizational vision and helping the agency become more customer oriented. External benefits include increased awareness and input and greater support

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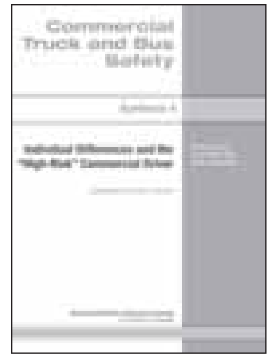

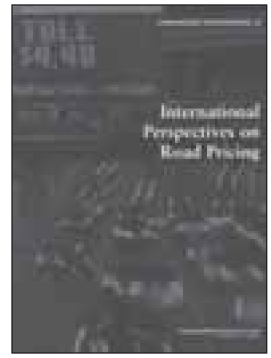

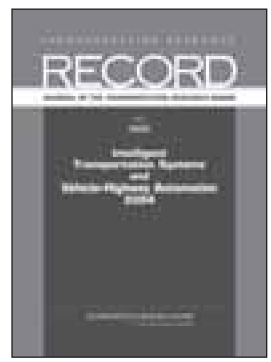

from local, state, and federal governments, the public, and local businesses.

2005; 44 pp.; TRB affiliates, $11.25; TRB nonaffiliates, $15. Subscriber category: public transit (VI).

Individual Differences and the "High-Risk" Commercial Driver
CTBSSP Synthesis 4
Commercial vehicle crash risk factors are identified and assessed to target the high-risk driver. Safety programs and practices—at both fleet- and industry-wide levels—are described.

2004; 83 pp.; TRB affiliates, $16.50; TRB nonaffiliates, $22. Subscriber categories: highway operations, capacity, and traffic control (IVA); safety and human performance (IVB); public transit (VI); freight transportation (VIII).

Training of Commercial Motor Vehicle Drivers
CTBSSP Synthesis 5
Training strategies and curricula from commercial driver training programs are identified and documented for potential use in improving commercial motor vehicle safety.

2004; 36 pp.; TRB affiliates, $14.25; TRB nonaffiliates, $19. Subscriber categories: highway operations, capacity, and traffic control (IVA); safety and human performance (IVB); public transit (VI); freight transportation (VIII).

International Perspectives on Road Pricing
Conference Proceedings 34
The International Symposium on Road Pricing, November 19–22, 2003, in Key Biscayne, Florida, was a collaborative effort of TRB, the Florida Department of Transportation, the Organization for Economic Cooperation and Development, and the Federal Highway Administration. The proceedings include two commissioned resource papers examining the evolution of congestion pricing and the state of the practice of road pricing outside the United States. Successes and challenges are explored, as well as the potential evolution of road pricing.

2005; 98 pp.; TRB Affiliates, $27.75; nonaffiliates, $37. Subscriber category: planning and administration (IA).

Intelligent Transportation Systems and Vehicle–Highway Automation 2004
Transportation Research Record 1886
This volume includes papers on the deployment of intelligent transportation systems in countries with transitional and developing economies; the parking guidance system in San Jose, California; emergency evacuation planning with microscopic traffic simulation; the South Jersey real-time motorist information system; and data requirements for enhanced digital maps in an advanced curve-speed warning system.

2004; 125 pp.; TRB affiliates, $33; nonaffiliates, $44. Subscriber category: highway operations, capacity, and traffic control (IVA).

Transit: Planning and Development, Management and Performance, Marketing and Fare Policy, and Capacity and Quality of Service
Transportation Research Record 1887
This multifaceted volume presents case studies of Chicago's regional transit program for welfare to work, the development of the Bay Area Rapid Transit system expansion criteria and process, the estimation of statewide urban public transit benefits in Tennessee, the travel demand and car ownership impacts of City CarShare in San Francisco, transit customer response to intelligent transportation system technologies in northern Virginia, and the application of the *Transit Capacity and Quality of Service Manual* to a bus corridor in Dublin, Ireland.

2004; 212 pp.; TRB affiliates, $40.50; nonaffiliates, $54. Subscriber category: public transit (VI).

Safety, Economy, and Efficiency in Airport and Airspace Management and Operations
Transportation Research Record 1888
Aviation topics examined in this volume include the expansion of airport capacity at London Heathrow Airport, trend analysis of controller-caused airspace incidents in New Zealand, the aviation network design in Taiwan, and the throughput effect of time-based metering at Los Angeles International Airport.

2004; 65 pp.; TRB affiliates, $29.25; nonaffiliates, $39. Subscriber category: aviation (V).

Pavement Management, Monitoring, Evaluation, and Data Storage 2004
Transportation Research Record 1889
This two-part volume examines information integration in budget planning for pavement management, integrating pavement management, and preventive maintenance; the effects of airport pavement-profile wavelength on aircraft vertical responses; and how variation in quarter-car simulation speed affects the algorithm for the international roughness index.

2004; 151 pp.; TRB affiliates, $37.50; nonaffiliates, $50. Subscriber category: pavement design, management, and performance (IIB).

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TRB PUBLICATIONS *(continued)*

Highway Facility Design 2004; Including 2004 Thomas B. Deen Distinguished Lecture
Transportation Research Record 1890
The research topics explored in this volume include dynamic actions on bridge slabs from a heavy vehicle's impact on roadside barriers, attributes and amenities of highway systems important to tourists, characteristics of snowmelt runoff from highways in the Tahoe Basin and the treatment investigations for improving the runoff quality, and issues in automating utility permits at transportation agencies. The text opens with the 2004 Thomas B. Deen Distinguished Lecture by Richard O. Jones, "Context-Sensitive Design: Will the Vision Overcome Liability Concerns?"

2004; 151 pp.; TRB affiliates, $37.50; nonaffiliates, $50. Subscriber category: highway and facility design (IIA).

Bituminous Paving Mixtures 2004
Transportation Research Record 1891
Authors assess the effects of moisture damage on material properties and fatigue resistance of asphalt mixtures, of a Superpave® defined restricted zone on hot-mix asphalt performance, and of different axle configurations on fatigue life of asphalt concrete mixtures. Papers in the volume also evaluate synthetic lightweight aggregate in hot-mix asphalt, the moisture sensitivity of bituminous mixtures, simple performance tests on hot-mix asphalt mixtures in the south central United States, and the dynamic angle validator.

2004; 237 pp.; TRB affiliates, $42; nonaffiliates, $56. Subscriber category: materials and construction (IIIB).

Design of Structures 2004
Transportation Research Record 1892
This 261-page, eight-part volume presents research on general structures, steel bridges, concrete bridges, dynamics and field testing of bridges, seismic design of bridges, tunnels and underground structures, culverts and hydraulic structures, and structural fiber-reinforced plastics. Also examined are the cost and performance comparison of U.S. overhead sign support structures, the behavior of steel bridges under superload permit vehicles, the current practice for design of high-strength concrete prestressed bridge girders, the field test and rating of the Arlington curved-steel box-girder bridge, decision aids for tunneling, and the fatigue behavior of a prestressed tubular bridge deck of fiber-reinforced polymer.

2004; 261 pp.; TRB affiliates, $43.50; nonaffiliates, $58. Subscriber category: bridges, other structures, and hydraulics and hydrology (IIC).

Concrete 2004
Transportation Research Record 1893
Research is presented on the durability of very-early-strength latex-modified concrete exposed to freeze–thaw and chemicals, the relationship between elastic modulus and permeability of damaged concrete, the air-void characteristics of concretes in different applications, and the ettringite deposits in air voids.

2004; 80 pp.; TRB affiliates, $30.75; nonaffiliates, $41. Subscriber category: materials and construction (IIIB).

Travel Behavior and Values 2004
Transportation Research Record 1894
The relationships between occupational, industrial, and sociodemographic characteristics and job start times; weekend activity and travel behavior in the Republic of Korea; mode choice of the elderly; and travel habits of home-based teleshoppers are conveyed in this record. A comprehensive econometric microsimulator for daily activity-travel patterns, a model for allocation of maintenance activities to household members, and a bilevel programming approach to optimizing a logistic distribution network with balancing requirements also are included.

2004; 257 pp.; TRB affiliates, $43.50; nonaffiliates, $58. Subscriber category: planning and administration (IA).

Transportation Planning and Analysis 2004
Transportation Research Record 1895
Authors examine the land use and transportation factors influencing congestion and jobs–housing imbalances for the Westside cities of Los Angeles County, Oregon's experience with a transportation utility fee, a smart growth study for Chicago, the calibration and validation of quick response forecasting parameters for cities in rural counties of South Carolina, and the implementation of an access management program in Texas.

2004; 227 pp.; TRB affiliates, $42; nonaffiliates, $56. Subscriber category: planning and administration (IA).

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

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes, whether they pertain to improved transport of people and goods or provision of better facilities and equipment that permits such transport. Articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by one or two illustrations that may help readers better understand the article.

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

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

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