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NCHRP

REPORT 525

VOLUME 12

**Making
Transportation
Tunnels Safe and
Secure**

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TCRP REPORT 86/NCHRP REPORT 525

TRANSPORTATION SECURITY

Volume 12:
Making Transportation
Tunnels Safe and
Secure

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WASHINGTON, D.C.

2006

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions*, published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation through research. In an objective and interdisciplinary setting, the Board facilitates the sharing of information on transportation practice and policy by researchers and practitioners; stimulates research and offers research management services that promote technical excellence; provides expert advice on transportation policy and programs; and disseminates research results broadly and encourages their implementation. The Board's varied activities annually engage more than 5,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. www.TRB.org

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FOREWORD

By S. A. Parker

Staff Officer

Transportation Research Board

This twelfth volume of both *NCHRP Report 525: Surface Transportation Security* and *TCRP Report 86: Public Transportation Security* is designed to provide transportation tunnel owners and operators with guidelines for protecting their tunnels by minimizing the damage potential from extreme events such that, if damaged, they may be returned to full functionality in relatively short periods. This report will be of interest to tunnel authorities, state and local transportation departments, other agencies responsible for tunnel operation and maintenance, enforcement personnel and first responders responsible for tunnel safety and security, and tunnel designers.

The objective of *Volume 12: Making Transportation Tunnels Safe and Secure* is to provide safety and security guidelines for owners and operators of transportation tunnels to use in identifying (1) principal vulnerabilities of tunnels to various hazards and threats; (2) potential physical countermeasures; (3) potential operational countermeasures; and (4) deployable, integrated systems for emergency-related command, control, communications, and information.

These guidelines were developed jointly under TCRP and NCHRP. They are appropriate for all modes of transportation.

Science Applications International Corporation, together with Parsons Brinckerhoff Quade & Douglas, Inc., and Interactive Elements, Inc., prepared this volume of *NCHRP Report 525/TCRP Report 86* under NCHRP Project 20-67/TCRP Project J-10G.

Emergencies arising from terrorist threats highlight the need for transportation managers to minimize the vulnerability of travelers, employees, and physical assets through incident prevention, preparedness, mitigation, response, and recovery. Managers seek to reduce the chances that transportation vehicles and facilities will be targets or instruments of terrorist attacks and to be prepared to respond to and recover from such possibilities. By being prepared to respond to terrorism, each transportation agency is simultaneously prepared to respond to natural disasters such as hurricanes, floods, and wildfires, as well as human-caused events such as hazardous materials spills and other incidents.

This is the twelfth volume of *NCHRP Report 525: Surface Transportation Security* and the twelfth volume of *TCRP Report 86: Public Transportation Security*, two series in which relevant information is assembled into single, concise volumes—each pertaining to a specific security problem and closely related issues. These volumes focus on the concerns that transportation agencies are addressing when developing programs in response to the terrorist attacks of September 11, 2001, and the anthrax attacks that followed. Future volumes of the reports will be issued as they are completed.

To develop this volume in a comprehensive manner and to ensure inclusion of significant knowledge, available information was assembled from numerous sources, including a number of state departments of transportation. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data and to review the final document.

This volume was prepared to meet an urgent need for information in this area. It records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. Work in this area is proceeding swiftly, and readers are encouraged to be on the lookout for the most up-to-date information.

Volumes issued under *NCHRP Report 525: Surface Transportation Security* and *TCRP Report 86: Public Transportation Security* may be found on the TRB website at <http://www.TRB.org/SecurityPubs>.

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Disclaimer: The contents within these guidelines reflect the best judgment and experience of Parsons Brinckerhoff Quade & Douglas, Inc. (PB), Science Applications International Corporation (SAIC), and Interactive Elements, Inc. (IEI), who researched and developed this book. The principal investigator for this project was Irfan Oncu (PB). Primary authors were Kevin A. Duffy (SAIC), Jaw-Nan (Joe) Wang (PB), Arthur Bendelius (PB), Gloria Hettinger (PB), Steve Lockwood (PB), Harry Saporta (PB), James Guinan (PB), and Dorothy Schulz (IEI).

P R E F A C E

This research project aimed to provide safety and security guidelines for transportation tunnel owners and operators. To accomplish this task, a team of experienced tunnel designers, builders, and operations personnel collaborated with safety and security experts to address the questions that a tunnel owner or operator may face in the post-9/11 environment, including the following:

- What natural hazards and intentional threats do I face?
- How would they be introduced?
- What are the vulnerable areas of my tunnel?
- How much of a disturbance would there be?
- How can I avoid these hazards and threats?
- How can I prepare myself for this disturbance if it occurs?

While risks to tunnels derive from both intentional threats related to crime and terrorism and hazards related to natural (i.e., unintentional) events, the risks often have the same tunnel vulnerabilities and damage potential and may share common countermeasures. Therefore, in this report, threat- and hazard-related characteristics and countermeasures are typically treated together in text and tables, except where specifically noted.

The recommendations for countermeasures presented in this report are intended for implementation by the tunnel owner or operator. This implementation may occur in part or whole depending on the local conditions and, importantly, the level of risk faced by the owner or operator. The owner or operator will also need to balance the implementation of structural and/or operational countermeasures with funding constraints. The countermeasures are presented as a menu of items that the owner or operator may select from. Issues of funding are not extensively explored in this report.

This report is organized into seven chapters:

- **Chapter 1, “Introduction,”** introduces the problems that this project has attempted to solve and the environment of the work. The chapter also describes the assumptions of the research team in approaching the work and defines the research terms.
- **Chapter 2, “Hazards and Threats,”** describes hazards and threats according to the areas or elements of the tunnel that might be affected, how the hazards and threats might be introduced, the operational and physical vulnerabilities to those hazards and threats, and the damage potential of the hazards and threats.
- **Chapter 3, “Case Studies,”** provides a chronology of past tunnel disasters that were studied for this project. The case studies researched the cause and effect of the disasters to glean pertinent information that may be applied in this research.
- **Chapter 4, “Tunnel Elements and Vulnerabilities,”** gives basic descriptions of various tunnel types, both by mode of transportation and by construction methodology. The chapter then outlines specific vulnerabilities by describing how and why failures can occur under safety- and security-related hazards and threats (e.g., fire or explosion) based on characteris-

tics of the tunnel's structure as well as the surrounding earth. The chapter rates the damage potential for various types of tunnels under explosion and fire events. The chapter also summarizes structural vulnerabilities and damage potential of the most extreme hazard or threat scenarios for road, transit, and rail tunnels.

The chapter presents a parallel analysis for mechanical, electrical, and communications (MEC) systems serving tunnels. These systems are described and categorized based on how critical they are to the continuing functionality of the tunnel and on the impact that system disruption would have. The chapter rates vulnerability versus critical location for the five MEC system types deemed to be the most critical. The system vulnerabilities and damage potential of the most extreme hazard and threat scenarios are summarized for road, transit, and rail tunnels.

- **Chapter 5, "Countermeasures,"** presents structural and system hazard and threat directories, in the form of tables, that summarize the information given in Chapter 4. The tunnel owner or operator is instructed how to apply these directories to his or her own facility and, by the process of elimination, identify which of eight countermeasure guides to consult. The countermeasure guides, which are also presented in the form of tables, refer the user to 50 possible countermeasures. The countermeasures are physical and/or operational methods for improving the structural and/or system elements of the tunnel. Within the guides, each countermeasure is supplied with the following:
 - Implementation (i.e., minimum required, deployed for an elevated threat level, or permanent enhancement),
 - Function and description,
 - Relative effectiveness,
 - Order-of-magnitude cost,
 - Physical or operational in nature,
 - Security strategy (i.e., deter, detect, interdict, or mitigate, including response and preparedness), and
 - Multiple-benefit potential.Directly following the guides, the 50 countermeasures are described in detail and are accompanied by sketches wherever possible. The countermeasure descriptions incorporate limitations of existing tunnels, types of construction, materials used, and the current tunnel environmental conditions. The recommendations are intended to improve the operational safety and structural integrity of the tunnel when exposed to a hazard or threat.
- **Chapter 6, "System Integration,"** provides information on current and proposed integrated systems that may be used to increase the safety and security of a transportation tunnel.
- **Chapter 7, "Future Research,"** provides recommendations for areas requiring further study and approximate funding costs. The areas of future research include 26 items with various cost and schedule estimates.

The report concludes with a list of references that were cited in the text, a list of additional sources, and a list of abbreviations.

Abbreviations and acronyms used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation