NUMBER 309

MAY–JUNE 2017

TR NEWS

Transportation and the Economy

Interconnections, Interventions, and Interdependencies

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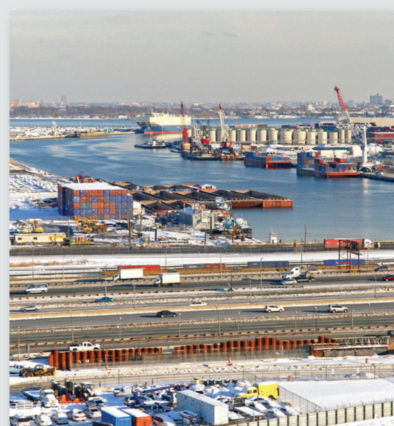

COVER: Infrastructure improvements at the Port Newark Container Terminal in New Jersey helped reduce truck congestion and greenhouse gas emissions. Articles in this theme issue examine the economic effects of transportation and infrastructure investments, methods for asset valuation, innovative freight modeling, and more. (Photo: Doc Searls/Flickr)

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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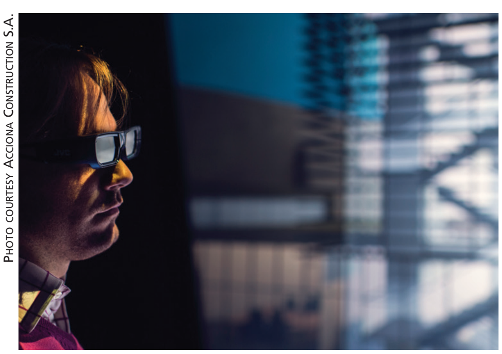
PHOTO COURTESY ACCIONA CONSTRUCTION S.A.

Research and development for major projects by Spanish contractor Acciona Construction—such as building information modeling and composite materials—facilitate technology transfer to the construction industry as a whole.

Moving research into practice is the theme of feature articles in the July–August magazine—the implementation of new technologies and research findings in the real world of the practitioner and the transportation system user. Authors describe today's successes, present a systematic approach that has proved effective at a state department of transportation, describe federal programs encouraging innovations at the state level, discuss initiatives by research programs to promote and document the implementation of results, and offer insights on technology transfer in the United States and in Europe, as well as tips on effective public relations, gathering practical ideas at conferences, assessing an agency's technological readiness, and more.

INTRODUCTION

Transportation and the Economy

Exploring the Conundrum

ANDREW C. LEMER

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A vibrant economy and people's well-being somehow are related to—and perhaps depend on—an effective transportation system. Archeologists and historians have noted that the earliest evidence of manufactured roadways dates back nearly six millennia to the civilizations of the Middle East and Asia (*1*). The ancient remnants of roads and of canals and ports around the world offer persuasive evidence that human societies early on recognized the value of investment in transportation infrastructure.

In Part 3 of his influential 1776 text *The Wealth of Nations*, Adam Smith assigned central government an essential role in constructing and maintaining public works and institutions that are advantageous to society as a whole but that cannot be profitable for any individual or group to establish (2). Smith cited public works and institutions for facilitating commerce, and he gave particular attention to transportation.

The founders of the United States recognized that investments in transportation would knit together the dispersed postcolonial cities and towns and would open the vast frontiers to settlement. In 1808, Albert Gallatin delivered his *Report of the Secretary of the Treasury on the Subject of Public Roads and Canals*. Although politics has shaped internal improvements, the Erie Canal, the National Road, the Baltimore and Ohio and the Pennsylvania railroads, and others were instrumental in the commercial ascendancy of New York, Philadelphia, and Baltimore, and the later completion of the transcontinental railroads laid the foundation for the economic power of Chicago, Denver, and Salt Lake City.








Photo: Taha Tahir/Wikimedia Commons

The Grand Trunk Road in modern-day Lahore, Pakistan, is an example of the lasting effects of transportation infrastructure investment. The highway was first built by the Mauryan Empire in 300 BC and still carries traffic.

Measuring the Benefits

Today the nation relies on a complex, well-articulated, and still evolving network of transportation infrastructure and logistics systems that deliver fresh vegetables in all seasons, the latest in fashions, and a cornucopia of other goods to local stores and directly to homes throughout the nation. When adverse weather or seismic events disrupt the system for more than a few hours, people experience a hint of life without the access and mobility that are routine.

The movement of people and commodities indicates economic activity, and this activity requires an effective transportation system. The worth of that system depends on what people do with it. Although the importance of the transportation system seems obvious, precise and convincing measurements of the benefits of particular and of aggregated investments in the system are surprisingly elusive.

With their 1981 book *America in Ruins: Beyond the Public Works Pork Barrel*, Choate and Walter identified the nation's "infrastructure crisis" and initiated more than a decade of intense debate among economists about returns on investments in public works. The Transportation Research Board (TRB) and its National Cooperative Highway Research Program (NCHRP) sought to inform the debate through NCHRP Project 02-17(1): Methodologies for Evaluating the Effects of Transportation Policies on the Economy, completed in 1991,[1] and NCHRP Project 02-17(3): Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance, completed in 1994.[2]

Photo: Library of Congress Prints and Photographs Division

Albert Gallatin authored the *Report of the Secretary of the Treasury on the Subject of Public Roads and Canals* in 1808.

A détente of sorts was reached in the debate, with the understanding that economically justifiable transportation investments yield positive returns comparable at least to the cost of the public borrowing to finance the development. Nevertheless, questions remain, and research continues, as a shelf of TRB publications (see box, page 6) and the feature articles in this issue of *TR News* demonstrate.

The articles address a sampling of the issues that are challenging researchers and decision makers on transportation's role in the economy. Transportation investments compete against a range of potential uses for public funds; proponents of transportation investment must not only produce credible arguments but also make the case convincingly in public forums.

These forums bring together the diverse interests of transportation users—travelers and businesses; the neighbors of transportation facilities; the workers who construct facilities, operate vehicles, and provide transportation services; other beneficiaries; and sometimes those who have suffered harm as a result of transportation investments. These stakeholders shape decisions about specific investments, such as the location of highway interchanges or transit lines, and influence the processes for resolving conflicts and reaching a compromise.

A Powerful Technique

Benefit–cost analysis has become a ubiquitous tool for justifying specific investments in transportation facilities and for assessing the relative merits of alternative investments. Those who use the technique seek to determine ways to achieve the greatest possible benefits from a given level of investment, or to identify from among several proposed investments the one likely to yield the greatest return in proportion to the investment—the one that achieves the highest benefit–cost ratio. The procedure shares similarities with cost-effectiveness analysis, which finds the least costly way of meeting the minimum acceptable levels of quality or standards of performance.

Authors Alexander Heil, Mark Seaman, and David Vautin discuss applications of benefit–cost analysis at the Port Authority of New York and New Jersey and at the Bay Area's Metropolitan Transportation Commission; both organizations are owners and operators of large portfolios of transportation services and must ensure the greatest possible returns on investments. The method requires detailed modeling to forecast the influence of a proposed investment on transportation and economic activity. Nevertheless, the benefits and costs associated with transportation include components that have no market values—for example, time savings or unobstructed views—and this complicates

[1] Findings were published as *NCHRP Report 342, Primer on Transportation, Productivity and Economic Development*, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_342.pdf.
[2] Findings were published as *NCHRP Report 389, Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance*, http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_389.pdf.

Photo: Andrew J. Russell/Yale University Libraries

A "golden spike" ceremony marked the completion of the First Transcontinental Railroad on May 10, 1869—and the dawn of Midwestern and Western cities' economic power.

the measurements and triggers debate among the diverse stakeholders.

Despite the difficulties, benefit–cost analysis and its variants are the most sophisticated approach for considering the allocation of limited resources to achieve economic and other societal benefits. Although the New York and San Francisco regions are not free of congestion, pollution, underserved markets, or other indications that their transportation systems need improvement, their economic vitality and decades of growth suggest that decision makers have been doing something right. Nevertheless, the authors note that benefit–cost analysis is a powerful technique that must be used with care.

Insights from Data

Obtaining sufficient amounts of good-quality data to support estimates of future transportation and economic activity presents a persistent challenge for analysts. Regional agencies and state departments of transportation (DOTs) conduct surveys, count traffic, and maintain extensive databases to support investment decision making.

Federal agencies also play key roles. Every five years, working with the Bureau of Transportation Statistics (BTS), the U.S. Census Bureau conducts the Commodity Flow Survey (CFS), a nationwide sampling of shipments from manufacturing, mining, wholesale, and selected retail and service establishments. The survey collects information on the commodities shipped, the origin and destination of the shipments, and their value, weight, and mode of transportation.

Because freight movement closely correlates with economic activity, the CFS data are useful in forecasting the demand for transportation and in gauging regional development and economic competitiveness. The CFS recently added an experimental data product with more detailed information on approximately 4.5 million shipments from businesses that participated in the 2012 survey; the product provides shipment-level information but protects the confidentiality of the businesses. Author José Holguín-Veras discusses ways to use these data to estimate freight production, determine where investment may be needed to avoid bottlenecks, and monitor the geographic patterns of

By creating a transportation hub at its historic Union Station, the small Mississippi town of Meridian invigorated its economy and strengthened its connection to the regional transportation network.

Photo: Visit Mississippi

Photo: Massachusetts DOT

A surveyor works on a Massachusetts Department of Transportation road reconstruction project. Traffic data and surveys help support transportation investment decisions by state agencies.

freight activity—valuable insights into the economic vitality of a region.

Perspectives on a region's economy and on transportation's role often shift toward the macroeconomic. Authors Theresa Firestine and Karen White discuss how BTS has been working to establish Transportation Satellite Accounts (TSAs) to supplement the input–output accounts maintained by the Bureau of Economic Analysis in the U.S. Department of Commerce. Policymakers and businesses use the input–output accounts to study industry interactions, productivity trends, and the changing structure of the U.S. economy.

Many economists had recognized that transportation's contribution was grossly underestimated—most national economic measures counted only the value of for-hire services, neglecting, for example, the activities of manufacturers who moved parts and products with their own fleets of vehicles. Better accounting will lead to better decisions.

Growth and Stimulus

Randall Eberts, no stranger to the debates over the productivity that results from capital investment in transportation, points out that patterns of economic activity in a region determine the infrastructure's worth; as the patterns change, so does the value. In addition, what appears to be investment-driven growth in one place may be a shift of development from one place to another. For example, a state or metropolitan area may capture a factory and its jobs by using transportation improvements to offer the corporate owners a more favorable deal than that from a rival area. The consequences, however, have little net benefit for the nation. As a transportation system matures, traditional analysis tools begin to fail—identifying transportation links and mode choices that would improve the system or the areas that would benefit from new or expanded facilities becomes all the more difficult.

Nevertheless, the construction of new and expanded facilities looks like progress and can give idled workers jobs. Investments in transportation may be politically attractive even when the economic justifications are unclear.

Joseph Morris describes a TRB study of the results of the American Recovery and Reinvestment Act of 2009 (ARRA), an initiative intended to

Transportation Investment and the Economy

Select TRB Publications

NCFRP Report 12: Framework and Tools for Estimating Benefits of Specific Freight Network Investments, 2011.

NCHRP Report 342: Primer on Transportation, Productivity, and Economic Development, 1991.

NCHRP Report 389: Macroeconomic Analysis of the Linkages Between Transportation Investments and Economic Performance, 1997.

NCHRP Report 786: Assessing Productivity Impacts of Transportation Investments, 2014.

NCHRP Synthesis 459: Using the Economic Value Created by Transportation to Fund Transportation, 2014.

NCHRP Web-Only Document 100: Examples of Best Practices for Communicating the Economic Benefits of Transportation, 2007.

SHRP 2 Report S2-C03-RR-1: Interactions Between Transportation Capacity, Economic Systems, and Land Use, 2012.

TCRP Web-Only Document 56: Methodology for Determining the Economic Development Impacts of Transit Projects, 2012.

TRB E-Circular 202: Transportation Investment for Economic Development: Making the Case, 2015.

Note: Search for any title above in the TRB Publications Index, http://pubsindex.trb.org/; the listing includes a link to the electronic document.

Photo: Payton Chung/Flickr

A well-known example of adaptive reuse, the High Line Park in New York City was built on an elevated section of a disused New York Central Railroad spur.

reduce the effects of the severe 2007 recession and to speed recovery. ARRA appropriated $48.1 billion mainly for grants to state and local governments for capital expenditures on roads, transit, passenger rail, and marine, aviation, and multimodal projects. Administered by U.S. DOT, the spending targeted projects already shown to have positive benefit–cost ratios. Although focused on the effectiveness of transportation spending as a fiscal stimulus during a recession—not on the long-term contribution of transportation investment to the growth of income in the economy—the TRB study found that careful project selection and construction-enhanced public expectations of growth can magnify the stimulus benefit and ultimately the likelihood of growth.

Adapting to Changes

The Greek philosopher Heraclitus observed, “The only thing constant in life is change,” an apt maxim for the transportation system’s role in the economy. Changes in the locations of people and jobs and in the operations of businesses shift the demands for access and mobility, causing gridlock on some roads, while others formerly busy grow quiet.

As Chandler Duncan and Anne Morris note, some portions of the system may become obsolete and unproductive. Some communities are turning to the adaptive reuse or “right sizing” of bridges, rail lines, and roads to reinvigorate obsolete investments in their local transportation systems.

The opening of the Erie Canal in 1825, the completion of the first transcontinental railroad in 1869, the establishment of domestic air mail in 1918, and President Eisenhower’s signing of the Federal-Aid Highway Act of 1956 to create the Interstate system are some of the landmarks of U.S. transportation that have had profound effects on the nation’s economy. With the advent of new industries and new technologies, questions about transportation’s role in economic development and about the value of investments in transportation will continue as fertile topics for research and debate.

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PHOTO: UTAH DOT

Investment in Transportation Infrastructure

A Case for Benefit–Cost Analysis

ALEXANDER HEIL, MARK SEAMAN, AND DAVID VAUTIN

Heil is Chief Economist, Port Authority of New York and New Jersey, New York; Seaman is Senior Economist, New York City Department of Transportation; and Vautin is Senior Planner–Analyst, Metropolitan Transportation Commission, San Francisco, California.

Despite the division over many public policy questions in Washington, D.C., the need for investments in infrastructure is one issue on which everyone apparently agrees. Prominent leaders have decried major U.S. airports as “third world” (*1*), and the American Society of Civil Engineers has given some categories of U.S. infrastructure a grade of D or D– (2).

Investment in infrastructure can have a profound impact on the economy—infrastructure improvements can boost productivity by providing faster and more reliable commutes, safer streets, and cleaner air. But all too often, the assessment of actual projects has overlooked economic benefits and has focused instead on the immediate impacts for the construction industry.

Although a boost in spending can yield a temporary increase in construction jobs, the primary justification for investing in infrastructure should be the long-term improvements for all of society. By weighing these benefits, transportation agencies can improve decision making on infrastructure investments.

Economic and Societal Benefits

Transportation infrastructure provides access, and the level and quality of that access has economic implications. Faster and more reliable travel means that people spend more time where they want to be. Safer travel prevents deaths and injuries that inflict a toll on society. Low-emissions travel means better

(*Above*:) Utah Department of Transportation workers prepare a ramp for a new bridge deck. The long-term economic benefits of infrastructure investment include increased safety, better traffic flow, and added capacity.

public health today and decreased burdens on future generations that will have to adapt to a changed climate.

Following are some of the benefits commonly included in estimates for transportation projects:

◆ **Time savings**. Transportation is mostly a means to other ends—fast and reliable travel is a primary goal of most transportation systems. Satellite navigation technology for aircraft, new train lines, and smart road designs are among the many measures that can trim travel times for people and cargo. For instance, New York's new Second Avenue subway speeds the commute for thousands who have a shortened walk to the new line, while riders on the parallel Lexington Avenue line are less likely to face delays from crowding.

◆ **Accessibility improvements**. Adding capacity can greatly increase the catchment area of a facility within the region. For instance, depressing the Central Artery in Boston and extending Interstate 90 have improved access to Logan Airport. Thousands more residents now live within a 45-minute driving distance of the airport. This type of benefit relates to travel time savings but quantifies a project's improvements by counting the increase in population, labor force, or employment within a given radius of travel time.

◆ **Safety improvements**. Projects that reduce injuries and fatalities provide obvious societal benefits; in economic terms, the projects cut medical costs, save productivity, and reduce pain and suffering. Traffic calming measures, computerized train controls, and airport runway safety areas may result in safer travel. For example, New York City's separated bike lanes have decreased injuries among all users of the targeted streets by 20 percent.

◆ **Reliability improvements**. Enhancing infrastructure and expanding capacity can shorten wait

Photo: NASA

NASA's FutureFlight Central uses 360-degree simulation to test new, satellite-based air traffic management technologies and concepts, which can lead to shorter travel times. Time savings are a key benefit from transportation projects.

times and decrease the variability in travel times. Travelers who can depend on and plan for journeys of certain, nonvarying duration can benefit from having to build less buffer time into their travel schedules. Bus rapid transit, for example, is providing faster, more reliable travel times in cities around the world, particularly when the buses run in dedicated lanes.

◆ **Environmental benefits**. Shorter travel times and less congestion can reduce air pollution and carbon emissions. For example, investments in GPS technology for aviation navigation are expected to make routes more efficient, lowering aircraft emissions. Similarly, for surface vehicles, shortened drive times and decreased congestion may reduce air pollution and greenhouse gas emissions.

Estimating Value

To estimate the value of these benefits, economists forecast the size or extent of each benefit and its value to society—not only the dollar savings but any type of economic gain.

For example, when the Port Authority of New York and New Jersey considered a series of roadway improvements for the New Jersey port facilities, the

Photo: Rene Schwietzke/Flickr

The I-93 tunnel through Boston, part of the Central Artery and Tunnel Project, moves people more quickly across the city and to high-volume destinations, such as Logan Airport.

New York's dedicated bus lanes allow travelers to move around the city quickly and reliably.

Photo: NACTO/Flickr

agency began by projecting future traffic levels along each section of road. Detailed traffic models were developed to estimate the travel times for drivers, with and without the proposed improvements. The time savings were multiplied by the value of time—for trucks, this was the hourly cost of doing business; for cars, this was the economic benefit for each vehicle, estimated from studies of driver behavior.

Because the improvements also were expected to reduce the amount of time that trucks were stuck idling in traffic, the analysis also tabulated the reduction in diesel emissions and related air pollutants. The total tonnage of pollutants was multiplied by a value per ton, primarily reflecting the health care savings from cleaner air.

The total benefit for each roadway improvement was tabulated separately and compared against the investment expenditure to derive a benefit–cost ratio; this information could assist in prioritizing the projects. For example, a project with a benefit–cost ratio of 3.2—that is, with $3.20 in benefits for every $1.00 in costs—might receive priority over a project with a ratio of 1.5.

Powerful Tool

This analytical approach requires planners to estimate the actual effects of projects and can serve as a powerful tool for decision making by public agencies. A proper benefit–cost analysis can identify the beneficiaries of a project, as well as the potential losers. This can help in deciding about who pays for a project and in shaping the project.

Applied to a portfolio of proposed projects, benefit–cost analysis can help direct funding to the projects that will deliver the biggest bang for the public's buck. Agencies frequently prioritize projects within buckets—one bucket for bridge projects, another for transit projects, and so on—because of the difficulties in comparing different classes of projects. By translating the benefits into a common currency, benefit–cost analysis allows agencies to compare projects across categories.

Application of benefit–cost analysis requires care. A single number, the benefit–cost ratio can summarize the results, with values greater than 1.0 indicating that the benefits are greater than the costs, and the temptation is to present that number as a definitive answer. Sensitivity analyses—includ-

Road improvements around the Port Newark Container Terminal were part of an infrastructure investment project to reduce truck congestion and to help eliminate the greenhouse gas emissions caused by idling trucks.

Photo: Doc Searls/Flickr

Photo: Billie Grace Ward/Flickr

The Port Authority of New York and New Jersey used benefit–cost analyses in decision making about facility projects, to increase ridership on its multimodal services.

ing advanced techniques such as Monte Carlo simulation—and the presentation of results as ranges are ways to ensure consideration of the underlying uncertainties and risks.

Appropriate Applications

Large public-sector agencies like the Port Authority of New York and New Jersey have long recognized the need to view transportation investments through the lens of benefit–cost analysis. Analyses of individual projects, as well as the prioritization of parts of the agency's overall capital plan, frequently have applied these principles.

For instance, road access to port facilities at Port Jersey and Elizabeth during peak hours can bottleneck from traffic delays. The port planning staff therefore worked to select road improvement projects that would alleviate the delays. A rigorous benefit–cost analysis led to the funding of a series of projects that have improved the flow of cargo in and out of the port.

Staff at the Port Authority have considered applying benefit–cost analysis to a larger set of system-enhancement projects. For example, several proposed projects would have expanded transit capacity for the PATH line by increasing the frequency of the trains, as well as the capacity of the stations throughout the system. Transportation analysis had shown that addressing peak period usage would yield improvements for riders. Adding capacity during the peak period, however, can be extremely expensive. Benefit–cost analysis was critical in weighing the value provided to the public against the cost of each project.

Transitioning to Adoption

In practice, few U.S. state and local agencies consistently have incorporated benefit–cost analysis into project planning. A 2016 Federal Highway Administration study found that benefit–cost analysis is "the exception, not the rule" among state departments of transportation (*3*). Technical challenges and a lack of institutional support have slowed adoption of benefit–cost analysis at the state level, and the study

Photo: U.S. Army, Patrick Bloodgood/Flickr

Floodwaters from Hurricane Sandy closed the Hoboken Station elevators in New Jersey. Life-cycle cost analysis assisted the Port Authority in considering options for improving flood resilience at the station.

found little change since 2005.

In comparison with some of its peer state agencies, the Port Authority of New York and New Jersey may be more advanced in applying benefit–cost analysis but still has a way to go. The agency requires that all projects undergo a life-cycle cost analysis, a simpler analysis that weighs the long-term cost implications of project alternatives without quantifying the benefits.

This limited approach still can greatly improve project decision making and can save agencies money, by forcing an exploration of future operating and capital costs. For example, the Port Authority recently assessed options for improving the flood resilience of an elevator at the PATH station in Hoboken, New Jersey. The cheapest alternative would be stop logs, a system of waterproof panels that could be deployed around the elevator before a severe storm.

The life-cycle cost analysis, which required an estimate of annual costs, revealed that the panels would have to be transported from a remote storage site each year for testing. This not only caused the annual costs to balloon but highlighted the inappropriateness of the solution in an emergency scenario. The findings prompted the agency to select an alternative solution—an aquarium glass perimeter wall—that had higher initial costs but much lower annual costs.

A Valuable Input

The Port Authority has developed a guidebook for comprehensively estimating project benefits and has applied the guidance to select projects. Additionally, in developing the agency's latest capital plan, the economics team conducted sketch-level analysis to prioritize smaller projects for inclusion.

CASE STUDY

Applying Benefit–Cost Analysis at the Metropolitan Transportation Commission

The San Francisco Bay Area's Metropolitan Transportation Commission (MTC) provides a strong example for the effective use of benefit–cost analysis. In the region's long-range planning process, proposed investments of more than $100 million must undergo two assessments—a quantitative benefit–cost analysis, to compare relative costs and benefits, and a qualitative targets assessment of the project's support of 13 regional targets.

Photo: VTA

Berryessa Station is part of the Valley Transit Area extension megaproject adding 16 miles of Bay Area Rapid Transit service in the Silicon Valley area.

To ensure consistency, the regional travel demand model runs each project through a simulation to yield a suite of user and societal benefits and disbenefits. Bay Area megaprojects, ranging from a heavy rail BART extension into downtown San Jose to a commuter rail tunnel linking downtown San Francisco with Silicon Valley, were evaluated in this manner, along with dozens of smaller-scale modernization and maintenance projects.

Ultimately, many of the Bay Area's efficiency and maintenance projects produced significantly higher benefit–cost ratios than did the expansion projects. Historically, many of the region's key expansion projects—from bridges to subways—were constructed during the New Deal and the post–World War II era, with rapid growth following. In the 21st century, land use policies focusing growth near infrastructure have made maintenance and modernization increasingly more critical than expansion into lower-density, slower-growth communities.

As shown in the accompanying bubble charts (Figure 1, page 13), system maintenance investments for highways, buses, and rail systems—along with cordon pricing, the BART extension to San Jose, and several urban bus rapid transit lines—proved cost-effective. Of these projects, transit improvements generally ranked higher in supporting the region's sustainability-oriented

Like many agencies, the Port Authority has prepared benefit–cost analyses for federal discretionary grants—such as TIGER, FASTLANE, the Airport Improvement Program, and storm resilience funds.[1] The required analyses have boosted the agency's internal capabilities by pushing the economics team to build tools that can be used in analyses of other projects.

A few agencies at the state and local levels have gone further and have incorporated benefit–cost analysis systematically into decision making (see sidebar, page 12). Although generally not the only criterion in these processes, benefit–cost analysis serves at a minimum as an extremely valuable input for informed debate on the merits of proposed projects.

[1] TIGER = Transportation Investment Generating Economic Recovery; FASTLANE = Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies.

This kind of debate will be critical to the success of any major surge in transportation infrastructure investment. Agencies looking to prioritize spending should consider the powerful insights that benefit–cost analysis can bring to the task.

For additional information on transportation benefit–cost analysis, consult the TRB Transportation Economics Committee website, bca.transportationeconomics.org.

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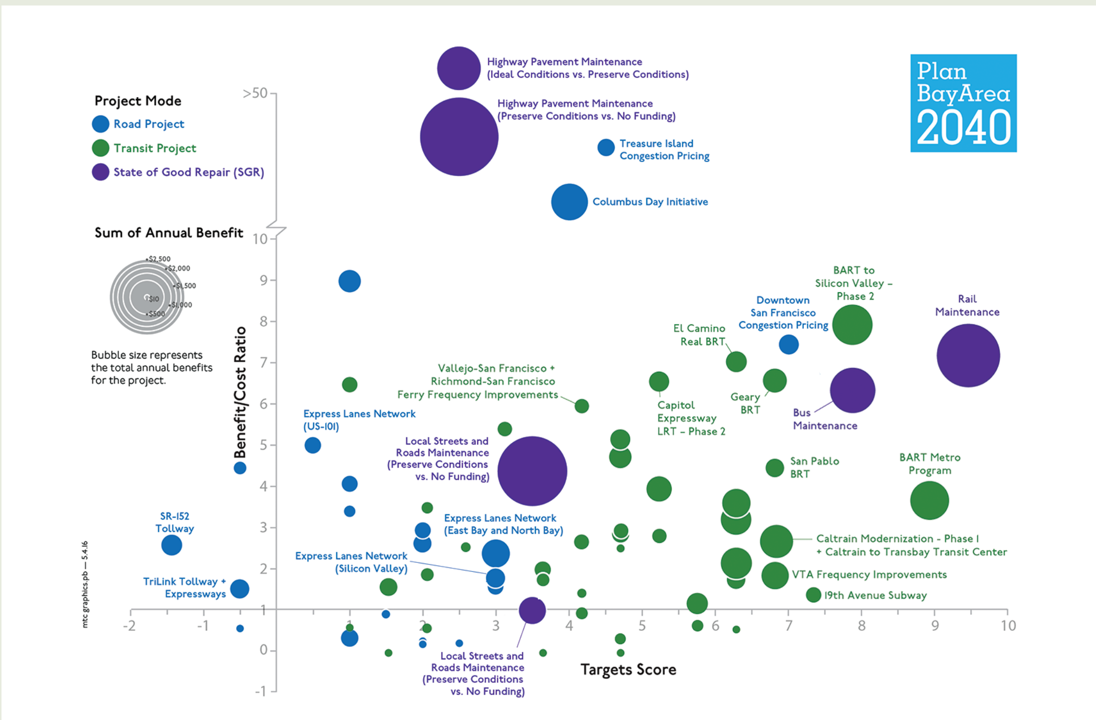


FIGURE 1 Project performance assessment results for road and transit projects, Plan Bay Area 2040.

targets than did the highway projects—in particular, the highway or tollway widenings at the periphery of the region that were identified as cost-ineffective.

MTC used the final benefit–cost ratios and targets scores—calculated consistently for all major regional projects—to identify high-performing projects for limited regional discretionary funding. Projects with benefit–cost ratios below 1 or with targets scores below 0 underwent a special "compelling case" process that required sponsors to appeal to MTC by specifying the limitations of the benefit–cost and targets analyses. MTC only approved the most compelling cases—with social equity often a critical, overriding consideration.

During both the 2013 and 2017 planning cycles, this quadrennial process realigned billions of dollars of funding from low-performing projects to investments in high-performing transportation projects.

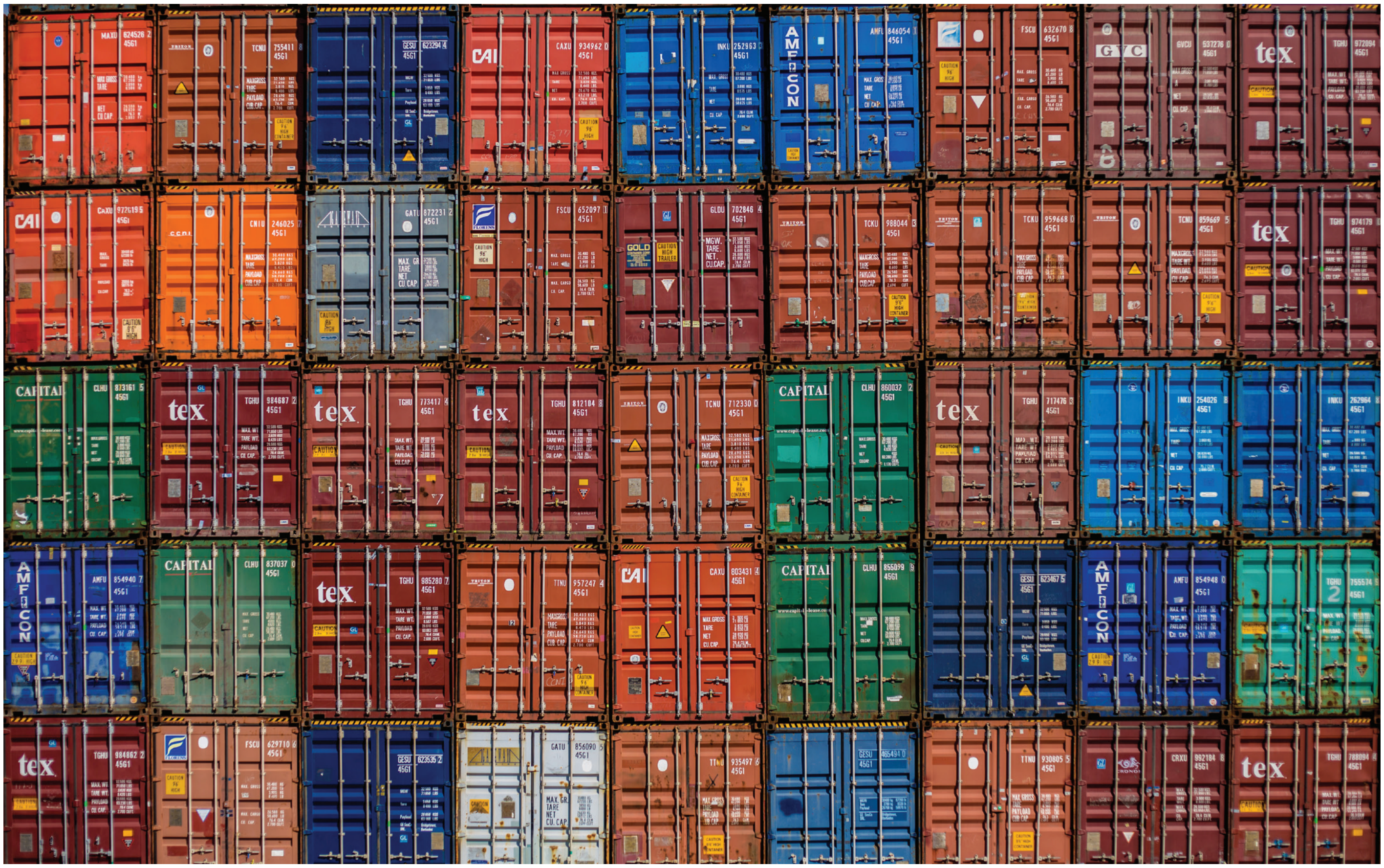


Photo: Blake.Thornberry/Flickr

Innovative Freight Production Models Using the Commodity Flow Survey

Improving Accuracy and Timeliness for Planning with Available Data

JOSÉ HOLGUÍN-VERAS

The author is William H. Hart Professor; Director, Volvo Research and Education Foundations Center of Excellence for Sustainable Urban Freight Systems; and Director, Center for Infrastructure, Transportation, and the Environment, Rensselaer Polytechnic Institute, Troy, New York.

A basic knowledge of the demand for transportation is essential in public-sector decision making. Estimates of current and future levels of demand are indispensable in planning for the infrastructure and for the transportation operations necessary to move people and goods. Timely information about emerging demands helps policy makers assess the need for responsive actions.

These considerations are especially important for freight. Freight activity is difficult to measure, because the operations primarily are conducted by private-sector companies, which are not inclined to share commercially sensitive data. In addition, the patterns of production and consumption of supplies can change quickly, without the awareness of public-sector policy makers.

Detecting Changes

Transportation agencies are not always equipped to foresee how changes in the local economy could affect freight activity and the usage level and performance of transportation networks. Agencies rely on monitoring devices that count traffic passing over various links in the network. Although relatively accurate, these devices provide information only for the equipped segments—typically, major highways and arterials. Rapid economic developments in areas outside those locations can go unnoticed.

Domestic oil production provides an illustrative

(*Above*:) The Barbour's Cut container terminal in Morgan's Point, Texas. Efforts to measure freight demand are complicated by changing consumption patterns and privately held data.

example. Although beneficial to the economy, the surge in the domestic production of oil and natural gas produced vast amounts of truck traffic, causing the deterioration of local roads not designed to handle the active flow of heavy vehicles. The volume of truck traffic and the impacts surprised most transportation agencies.

The inability to provide the transportation infrastructure needed for the oil extraction could constrain local economic development. The ability to monitor freight activity and take timely notice of changes in the geographic patterns of production and consumption of freight can help the public sector ensure that the transportation system can function as the circulatory system for the economy. Novel approaches are needed to provide timely and reliable estimates of freight activity throughout the country.

Freight Production Models

The Commodity Flow Survey (CFS), conducted every five years by the Census Bureau and the U.S. Department of Transportation's Bureau of Transportation Statistics, produces data on the movement of goods in the United States, providing information on commodities shipped, their value, weight, and mode of transportation, as well as the origin and destination of shipments from manufacturing, mining, wholesale, and selected retail and services establishments.

A National Cooperative Freight Research Program (NCFRP) project[1] has demonstrated that freight production models based on confidential microdata from the CFS can provide an efficient mechanism to monitor the geographic patterns of freight activity, using publicly available employment data (*1*). The models recognize that freight production is an economic process in which the various inputs—such as labor and capital—work together to produce the desired level of economic output. In this context, for a given technology of production, the output is largely determined by employment.

The models enable analysts to examine the geographic aspects of freight production in detail. Federal data collection programs and local administrative processes collect employment data at a high level of detail routinely and fairly frequently. Using employment data to infer freight activity is cost-effective. The geographic level of detail and the timeliness of the data make freight production models ideal for monitoring changes in the economic geography.

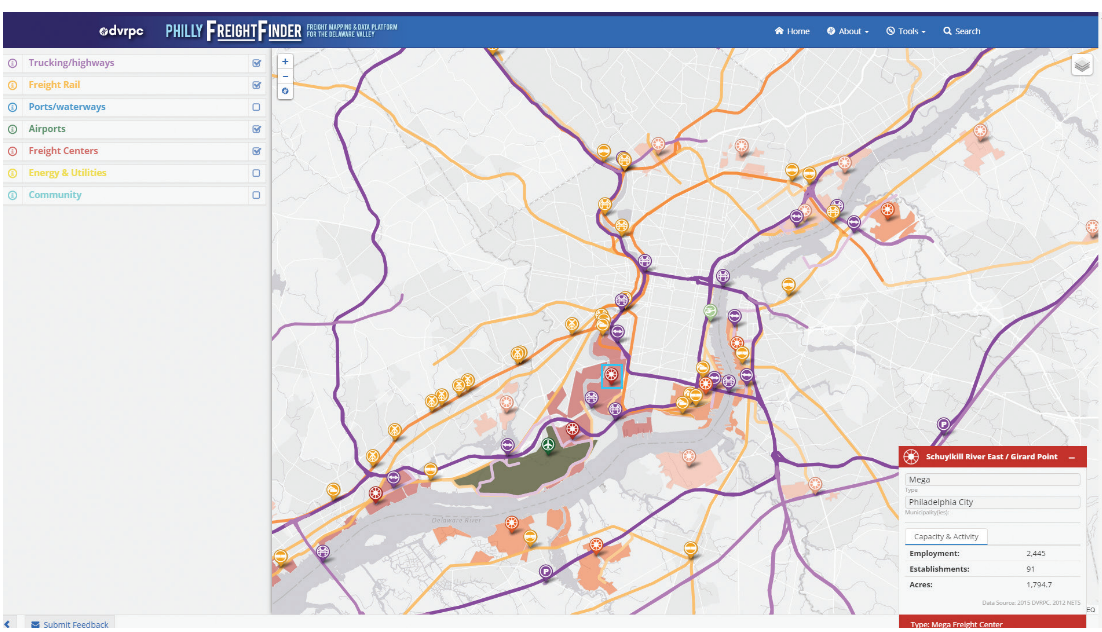
Freight production models are readily available. The NCFRP project demonstrated that the CFS microdata and other confidential datasets can generate estimates of freight production for five states—California, New York, Ohio, Texas, and Wyoming—and for the entire United States. The project produced more than 1,400 freight production models, linear and nonlinear, for 37 industry sectors (*1*). These models can estimate freight production at a range of geographic levels—for example, by establishment, block, zip code, or transportation analysis zone. The lessons learned from the test can improve the sample design of the CFS.

Monitoring Economic Geography

The interconnections between the economy and freight activity are profound. Freight activity is a chief

[1] NCFRP Project 25(01), Estimating Freight Generation Using Commodity Flow Survey Microdata, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3492.

Image: Delaware Valley Regional Planning Commission



PhillyFreightFinder is a freight mapping data resource created by the Delaware Valley Regional Planning Commission. Freight production models reflect the development of new technologies.

Photo copyright Rawpixel.com

Publicly available employment data can be used to infer freight activity and to monitor changes in economic geography.

physical expression of the economy—the transportation of supplies from points of production to points of consumption, where the cargo is processed, transferred, or stored.

These production–consumption links are the elementary components of modern production systems, which may have hundreds of production–consumption links. From a transportation point of view, understanding the geographic patterns of the production and consumption of freight is essential in assessing the need for infrastructure improvements and the potential for modal shifts.

Understanding these links is critical for assessing future needs. The amount of cargo that emanates from commercial establishments—that is, the freight production—influences the choice of mode and number of vehicles—that is, the freight trip production. Similarly, the amount of cargo that arrives at an area's establishments determines the freight attraction and the number of freight vehicle trips into the area—that is, the freight trip attraction.

The resulting freight vehicle traffic produces a host of externalities, such as pavement damage, congestion, pollution, and accidents. Freight policy must not only maximize the beneficial aspects of the production and consumption of freight but must minimize the negative impacts of freight traffic.

Freight production and attraction are economic processes. Production is the physical output of an establishment; freight attraction represents the flows of supplies needed to produce the output. The interconnections between freight activity and the economy are tight. Changes in the economy lead to changes in the geographic patterns of freight production and attraction—and to changes in the traffic generated.

Testing the Models

Transportation planners generally are interested in fine-level estimates of freight activity. Highly aggregated estimates of freight production are significantly less useful than highly disaggregated estimates, which can be directly related to conditions on the ground. A pure data collection approach that relies on direct surveys to produce the estimates, however, is not likely to deliver a desirable level of detail. The process is too expensive and time consuming to be practical.

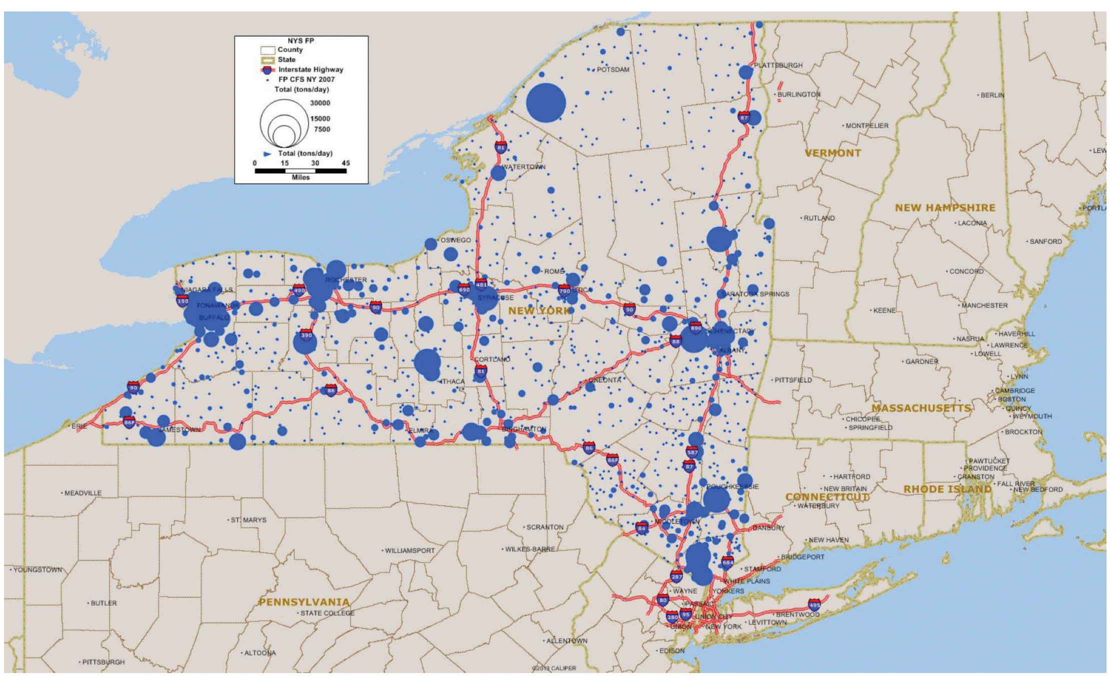


FIGURE 1 Freight production, New York State, 2007.

The CFS includes 100,000 establishments—a relatively small sample, representing 1.3 percent of the 7.4 million establishments in the United States. A 5 percent sample of establishments could cost more than $300 million and could take four years to produce results. This is neither feasible nor necessary. Instead, the innovative use of freight production models applying local employment data, together with complementary freight demand models, can provide a more pragmatic avenue to the information needed for transportation planning and decision making.

Figures 1 and 2 (page 16 and below) show freight production for New York State based on data from the Census Bureau at the zip code level. The estimates derive from the freight production models developed for NCFRP by Holguín-Veras et al. (*1*). The figures show the changes in economic geography during the 2008–2009 financial crisis, when freight production dropped.

The spatial changes in freight production are also evident. Arrows indicate locations with a large drop in freight production—the result of a significant reduction in mining. As in the case of domestic oil production, identifying changes in freight production in locations far from freight corridors is complex. Freight production models, however, can quantify these effects from readily available secondary data, yielding results useful for planning.

Enhancing the CFS

Freight production models also can indicate improvements to the sample design of the CFS and can expand the survey's geographic and industrial coverage. Freight production—one of the chief variables the CFS estimates—is not completely random; the results of the freight production models show this.

Freight production models have both a systematic, or deterministic, component and a random component. The systematic component represents the portion of the actual freight production that is captured by the model. The random component captures the inherent differences between businesses, production systems, and the like, which cause the data to deviate from the systematic pattern.

Reducing Data Needs

The higher the explanatory power of the model, the

PHOTO: WBEZ

Truck traffic near an Illinois mine for silica, a critical ingredient for domestic shale oil production. Increased heavy-vehicle traffic related to domestic oil production has caused many roads to deteriorate.

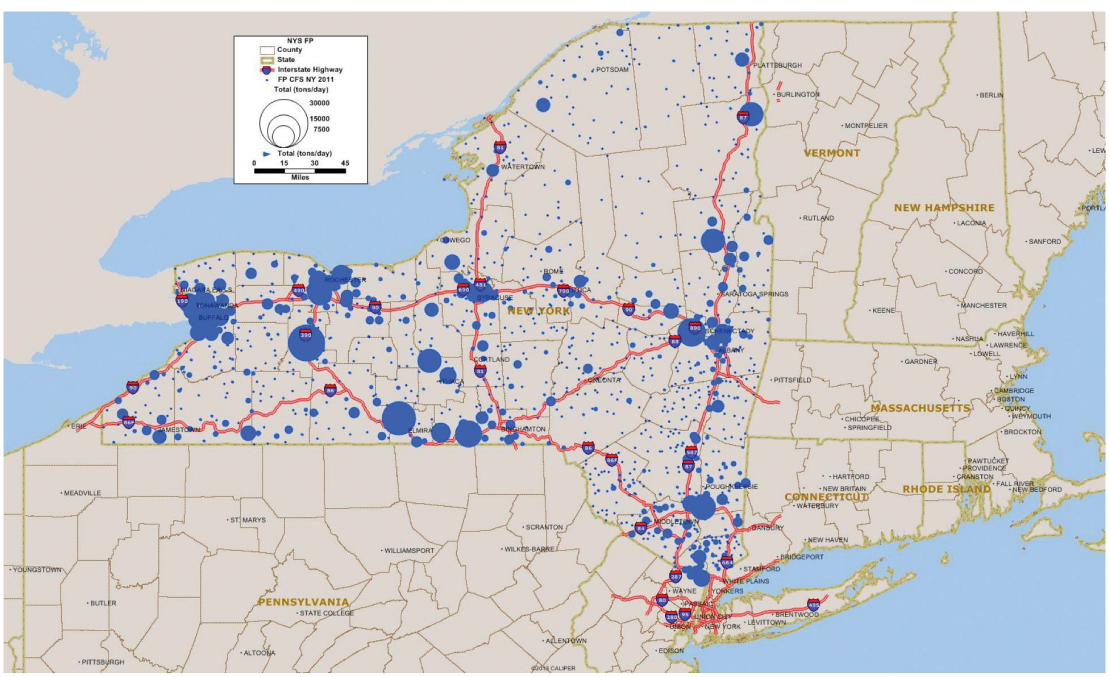


FIGURE 2 Freight production, New York State, 2011.

Tug *Defiance* and barge *Ashtabula* inbound at Buffalo harbor in New York. Models can incorporate secondary data to help quantify geographic and modal changes in freight production.

PHOTO: JEREMY MONIN/FLICKR

smaller the random component. Theoretically, a perfect model would eliminate the need to collect data—in this case, applying the model with the available employment data would estimate freight production correctly. At the other end, a model with zero explanatory power implies the lack of a systematic relation between freight production and the independent variables. If good models are not available, collecting data is the only option.

In most cases, real-life models work between these extremes and can explain only a portion of the variance in freight production. Exploiting the power of mathematical or econometric models will reduce the need for data collection, as experience in other, more mature fields of science indicates.

The evolution of research in structural engineering, for example, provides compelling examples of the value of models. Early on, the only way to test the ability of a physical structure to withstand forces was to conduct physical experiments with scale models of the various components; the designers of the great cathedrals in Europe used this technique.

Eventually, researchers developed highly accurate mathematical models that could predict the performance of any structure. Moreover, these models have provided insight beyond what could be achieved from physical tests, by computing to a minute level of detail the stresses and strains inside the various structural elements. Physical tests are no longer necessary for the design of most structures.

Better models reduce the need for empirical trials and data collection. Enhancing the capabilities of freight transportation modeling can achieve more with the limited resources available. Once a strategy of model data collection is embraced, the sample sizes can be reduced in proportion to the explanatory power of the corresponding models. This will increase the efficiency of transportation planning and will make possible the reallocation of resources to increase the geographic or industrial coverage of the CFS.

Gaining Temporal Stability

The temporal stability of freight production models is a key consideration. Understanding the distinction between freight production and freight production models is essential. Freight production represents the physical output of an establishment, which may go up and down according to the cycles of the economy. A freight production model is an econometric formula that expresses freight production as a function of an establishment's employment and other characteristics.

In a simplified manner, the freight production model reflects the production technology in use. Production technologies evolve at different rates, depending on the industry sector. An analysis of the temporal stability of freight production models over a long term—such as decades or centuries—must consider that all industry sectors are likely to change production technologies. For freight data collection, however, analysis of the short term—five years or less, corresponding to the time between editions of the CFS—is more relevant.

From this perspective, either the process is relatively static—that is, not changing during the period—or it is time-dependent and undergoing changes. In either case, the sample sizes for the various industry sectors could be reduced in proportion to the explanatory power of the corresponding model.

The chief insight is that a holistic strategy of model data collection will accomplish the same level of statistical accuracy as a data-only strategy, but with a smaller sample size. The agencies then can reallocate resources to collect data at a finer level of detail elsewhere, focusing either on geography or on the industrial sectors covered by the CFS.

Toward a Holistic Strategy

Nevertheless, collecting data from industry sectors that have good models for freight production remains necessary. Collecting even a minimal amount of data would enable transportation planners to validate and improve the current models and to assess whether fundamental changes have occurred in production patterns. If an industry sector exhibits a major change in production patterns, the sample sizes can be adjusted accordingly.

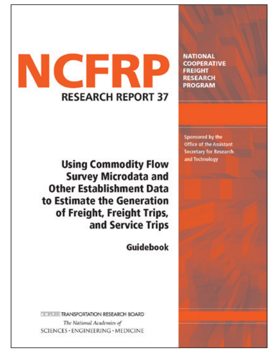
These are initial and tentative steps toward a holistic strategy that exploits the synergies between advanced modeling and targeted data collection. The key lesson is that advanced empirical research on freight production and basic research on freight demand modeling are extremely important.

The CFS is the only U.S. freight data collection program that could be used to quantify the interconnections of economic activity and the generation of freight. The survey therefore is an important resource that must be protected and enhanced to meet evolving data needs. A redesign could take advantage of potentially complementary sources, such as GPS data, administrative records, and data from the private sector.

Achieving this vision will necessitate a sustained research effort. Ultimately, this critical research will help practitioners across the country identify changes in the local economic geography that could affect the transportation networks within their jurisdictions and produce better freight plans. In addition, the results could help federal data collection efforts use public resources more efficiently.

Reference

1. Holguín-Veras, J., C. Lawson, C. Wang, M. Jaller, C. González-Calderón, S. Campbell, L. Kalahashti, J. Wojtowicz, and D. Ramirez-Rios. *NCFRP Research Report 37: Using Commodity Flow Survey Microdata and Other Establishment Data to Estimate the Generation of Freight, Freight Trips, and Service Trips: Guidebook*. National Cooperative Freight Research Program, Transportation Research Board, Washington, D.C., 2017.



NCFRP Report 37, *Using Commodity Flow Survey Microdata and Other Establishment Data to Estimate the Generation of Freight, Freight Trips, and Service Trips: Guidebook*, is available online at www.mytrb.org/Store/Product.aspx?ID=8445; for more information, visit www.trb.org/Publications/Blurbs/175283.aspx.

Photo: Western Area Power

Power transmission lines and facilities were upgraded to meet growing demand in the oil boomtown of Williston, North Dakota. Freight and economic activity are deeply linked.

Photo: Thomas Hawk/Flickr

The Economic Value of Using Transportation Assets and Services

Figures from the Transportation Satellite Accounts

THERESA FIRESTINE AND KAREN WHITE

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Transportation plays a vital role in many aspects of the American economy. Stating the value of transportation infrastructure—such as roads, railroads, ports, and airports—sheds light on the physical aspects, or presence, of transportation but misses the value that the economy derives from the infrastructure. The dollars expended on transportation services, plus the contribution of transportation services to the economy, are measures for the value derived from transportation infrastructure.

The U.S. Department of Transportation's Bureau of Transportation Statistics (BTS) has developed a measuring tool, called the Transportation Satellite Accounts (TSAs), to show not only the dollars expended on transportation for the production of goods and services but also the contribution of transportation to the total U.S. gross domestic product (GDP). The TSAs build on the input–output accounts developed by the Bureau of Economic Analysis in the U.S. Department of Commerce.

Dollar Values by Activity

The input–output accounts show how output from one industrial sector may become an input to another industrial sector of the United States. For the trans-

(*Above*:) Freight activity at the Port of Oakland in California. The Bureau of Transportation Statistics has developed a measuring tool to quantify the dollars expended on transportation, as well as the contributions of transportation services to the economy.

portation industry, the input–output accounts show the value of all for-hire transportation and list the industries that use for-hire transportation. For-hire transportation consists of the services provided by transportation firms to industries and the public for a fee; the service providers include air carriers, railroads, transit agencies, common carrier trucking companies, and pipelines (see box, page 22).

The TSAs reorganize the input–output accounts to show the dollar value of transportation activity carried out by nontransportation industries for their own purposes; this activity is called in-house transportation. The TSAs then add the dollar value of transportation for households using private motor vehicles—also known as the household production of transportation services (HPTS). The HPTS does not include the value of time for the household traveler, because that value is not within the scope of the input–output accounts. By design, the input–output accounts do not include unpaid labor, volunteer work, and other nonmarket production.[1]

In 2014, transportation's total estimated contribution was $1,001.9 billion (see Table 1, below right). For-hire transportation contributed $504.8 billion (2.9 percent) to the U.S. GDP of $17.7 trillion.[2] Transportation services by air, rail, truck, and water, provided by nontransportation industries for their own use—that is, in-house transportation—contributed an additional $187.2 billion (1.1 percent) to the GDP. Total household transportation, measured by the depreciation cost associated with households owning motor vehicles, contributed $309.9 billion (1.8 percent).

The total contribution of household transportation to the GDP was larger than that of any other

[1] For more information, visit www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/transportation_satellite_accounts/index.html.

[2] The GDP value in the TSAs includes the contribution of household transportation and therefore is larger than the GDP value published in the national accounts. Household transportation covers automobile transportation provided by households for their own use.

Photo: Direct Relief/Flickr

Many businesses and individuals rely on for-hire transportation such as FedEx to receive and deliver goods.

Photo: Bruce Stockwell/Flickr

Safe, reliable, and affordable transportation is critical for most Americans; economists seek ways to measure its economic value.

TABLE 1 Contribution of For-Hire and In-House Transportation to U.S. Gross Domestic Product (2014 dollars)

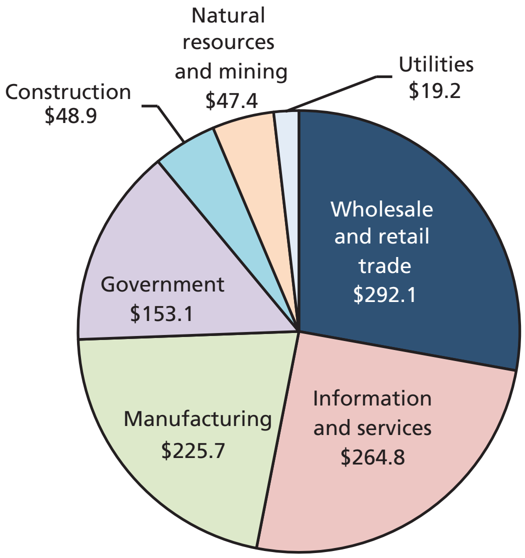
	Mode	Value Added ($ billions)	Share of GDP (%)
In-house	HPTS	309.9	1.76
	Water	4.8	0.03
	Rail	0.2	0.00
	Air	28.9	0.16
	Other	na	na
	Truck	153.2	0.87
For-hire	HPTS	na	na
	Water	17.5	0.10
	Rail	44.1	0.25
	Air	83.9	0.48
	Other	227.2	1.29
	Truck	132.1	0.75
Total for-hire		504.8	2.86
Total in-house		187.2	1.06
All transportation		1,001.9	5.67
GDP		17,658.0	100.00
GDP less transportation		16,656.1	94.33

Notes: HPTS = household production of transportation services; GDP = gross domestic product; na = not applicable.

Source: U.S. Department of Transportation, Bureau of Transportation Statistics, *Transportation Satellite Accounts*, www.bts.gov, March 2016.

FIGURE 1 Use of transportation by industry, 2014 (current dollars, billions).

SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, *Transportation Satellite Accounts*, http://www.bts.gov, March 2016.



Total use of transportation = $1,049.2 billion

transportation modes. Trucking contributed the second largest amount, $285.2 billion. In-house truck transportation operations contributed $153.2 billion, and for-hire truck transportation services contributed $132.1 billion. The size of trucking's contribution reflects the use of trucks by for-hire transportation and nontransportation industries for their own purposes.

Industry Analysis

Recent analysis by BTS further highlights the role of transportation by looking at the dollars expended on transportation services by seven major nontransportation U.S. industries (see Figure 1, left). Some industry sectors use more transportation than others. The wholesale and retail trade sector employed the most transportation services of any sector of the U.S. economy, according to the BTS webpage Industry Snapshots: Uses of Transportation.[3]

In 2014, the seven nontransportation sectors of the economy relied on more than $1 trillion in transportation services. The wholesale and retail sector used $292 billion, more than one-fourth (27.8 percent) of total transportation use. The service sector—information, financial services, professional and business services, education and health services, leisure and hospitality, and other services—also used one-fourth (25.2 percent) or $264.8 billion.

The report includes each sector's contribution to the GDP—nationally and by state in 2015, the sector's reliance on transportation by mode in 2014, the amount of transportation the sector required to produce $1 of output in 2014, the number of transportation and materials-moving workers employed by the sector in 2015, the median annual wage for selected transportation occupations in the sector in 2015, the number of trucks and number of truck miles accumulated by the sector in 2002, and shipment characteristics for selected sectors in 2012.

The amount of transportation required to produce $1 of output demonstrates each sector's reliance on transportation. In 2014, the wholesale and retail trade sector required more transportation ser-

[3] https://www.rita.dot.gov/bts/publications/industry_snapshots/uses_of_transportation_2015.

What Are For-Hire, In-House, and Household Transportation?

◆ **For-hire transportation** consists of the air, rail, truck, passenger and ground transportation, pipeline, and other support services provided by transportation firms, such as railroads, transit agencies, common carrier trucking companies, and pipelines, to industries and the public for a fee.

PHOTO: SOUNDER BRUCE/FLICKR

◆ **In-house transportation** consists of air, rail, water, and truck services produced by businesses for their own use. Business in-house transportation includes privately owned and operated vehicles of all body types, used primarily on public rights-of-way, and the services to store, maintain, and operate the vehicles. A baker's delivery truck is an example of business in-house transportation.

◆ **Household transportation** covers transportation provided by households for their own use and is measured by the depreciation cost associated with the household ownership of motor vehicles.

The retail and wholesale trade sector required 9.9 cents of transportation services to produce $1 of output in 2014—more than any other sector.

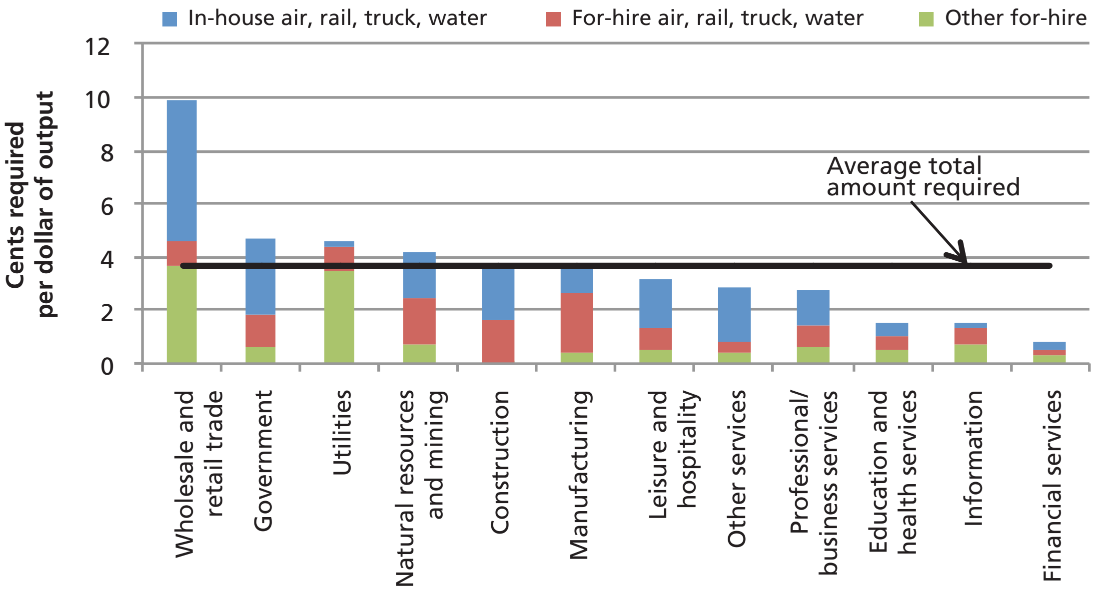


FIGURE 2 Transportation required per dollar of output, by sector, 2014.

Source: U.S. Department of Transportation, Bureau of Transportation Statistics, *Transportation Satellite Accounts*, http://www.bts.gov, March 2016.

vices to produce $1 of output than any other sector. The wholesale and retail trade sector required 9.9 cents of transportation services to produce $1 of output in 2014—with 5.3 cents of in-house truck transportation operations and 4.6 cents of for-hire transportation services (see Figure 2, above).

Economic Measurement

Ideally, economists would like to measure the value of health, welfare, and happiness enabled by access to safe, reliable, and affordable transportation. The BTS satellite accounts offer one avenue toward measuring the economic value of the transportation used by industries and households.

The economic value of using transportation assets and services is closely tied to the capacity, the availability, and the state of repair of the system. Further research is necessary to link transportation's contribution to the GDP directly to investments in transportation capacity, maintenance, and operations.

Photo: Madonovan/Flickr

The service sector of the economy, although considered to be a nontransportation sector, includes transportation-dependent services such as tour buses.






Photo: SounderBruce

Valuing a Mature Highway System

In Search of the Holy Grail

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For years, researchers have sought the one true estimate of the value of highway infrastructure—the single number that policy makers can use to ensure the country is equipped with an optimal network of highways. Despite the efforts of hundreds of studies, the search for the Holy Grail of highway valuation has proved quixotic.

In theory, no single estimate can express the value of transportation infrastructure. Because highway infrastructure has network characteristics

From congested urban areas (*above*) to rural roads (*below*), the many components of the Interstate Highway System create a challenge for estimating the value of transportation infrastructure.

Photo: Nicholas A. Tonelli

Photo: Erika Celeste/Michigan Radio

A strip mall on a reclaimed mine site in Logan County, West Virginia. As the economic drivers of an area change, so do the uses of its roads.

and serves the public good, the returns vary from one part of the highway system to another (*1*). For example, adding miles to a congested segment of an Interstate can improve traffic flow and safety. Consequently, measuring the value of highway infrastructure for a congested section of the Interstate system in a crowded metropolitan area would yield a higher return than for a deserted stretch of Interstate in the Great Plains, although both segments are part of the same network.

In addition, changing economic conditions may alter the value of highways over time, particularly at the subnational level. An example is access to the coalfields of West Virginia—as coal deposits are depleted, and as lower carbon-emitting fuels replace coal, the economic value of the roads supporting the coal industry decreases.

These theoretical and practical reasons impede the ability to estimate one ideal value for the effects of transportation infrastructure. Nevertheless, with the maturing of the highway system and the consequent need to understand and account for the transportation services that flow through the system, policy makers and practitioners today need a reliable estimate even more than in the past.

Supply and Demand

The highway system is at a mature stage of development. President Eisenhower's signing of the Federal-Aid Highway Act of 1956 led to the creation of the Interstate Highway System. Today, more than 220,000 miles of Interstate highways are in place, compared with only a smattering of four-lane, limited-access highways in a few states 60 years ago.

The period of great expansion of the Interstate system prompted an even greater increase in highway usage. Between 1980 and 2004, for example, vehicle miles traveled (VMT) on Interstate highways increased by 143 percent, while Interstate lane miles expanded by only 17 percent. Similarly, VMT on all other roads increased by 82 percent, but lane miles on those roads increased by only 5 percent.

Nevertheless, in the past 10 years, the relationship between increases in VMT and in lane miles has stabilized, suggesting a more mature system. Between 2004 and 2014, both VMT and lane miles for the Interstate Highway System increased at approximately the same rate—around 4 percent.

Furthermore, the number of ton-miles shipped by trucks decreased slightly between 2002 and 2012, although trucks claimed a higher percentage of total ton-miles shipped, and the value of truck shipments per ton increased by nearly 30 percent, after a decline in value between 1993 and 2002. Although the Great Recession undoubtedly has affected trends during the past 10 years, the highway system clearly is maturing.

This is consistent with the decline in the net rate

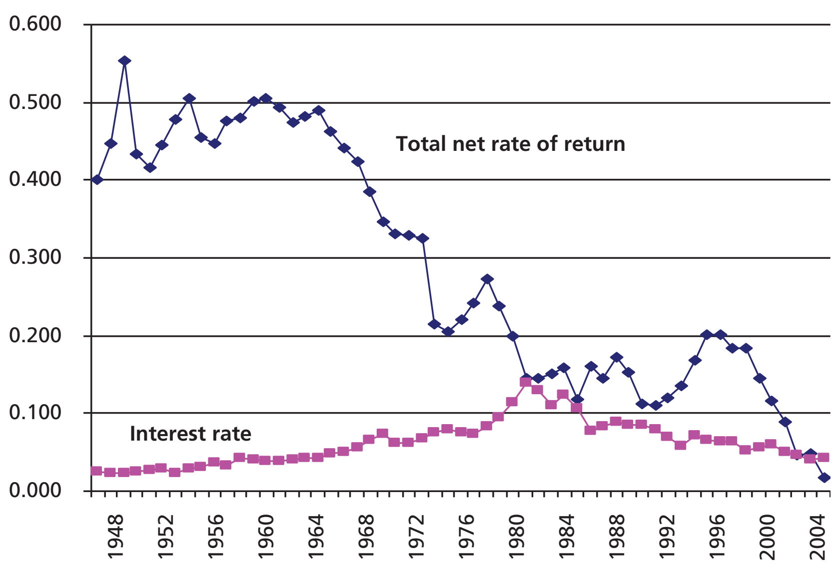

FIGURE 1 Net rate of return of highways and interest rates. [Source: Author's analysis of estimates by Mamuneas (*2*).]

of return from highways during this time. As shown in Figure 1 (above), Mamuneas finds that before 2004, the net rate of return was greater than the marginal cost of highway investment; this is consistent with VMT and ton-miles growing faster than the expansion of the highway system's lane miles (2). Starting around 2004, however, the marginal benefits and marginal costs converged; the convergence of highway usage and the expansion of lane miles is consistent with a mature highway system.

Although VMT per lane mile has leveled off in recent years, traffic on many portions of the U.S. highway system remains heavy. Nevertheless, building new highways appears less attractive, perhaps because the marginal benefit of an added mile of highway barely covers the marginal cost, as the estimates by Mamuneas suggest. If building new highways is less likely, then using the current roads with increased efficiency is imperative, to avoid an increase in travel time and a reduction in reliability and safety.

System Transformation

New Technologies

Instead of focusing on laying down asphalt and concrete, investment decisions will need to coordinate the public and private sectors to work together in transforming the highway system into much more than ribbons of pavement. The system instead will be a well-integrated network of pavements, embedded electronics, surveillance cameras, satellite images, and signals—an intricate maze on which intelligent vehicles will navigate.

For the public and private sectors to make the appropriate investment decisions to bring these technologies together, accurate pricing for the components and accurate estimates of the returns, individually and together, are a necessity. Private-sector businesses are likely to be reluctant to invest in the development of new technologies for highway transport without knowing with reasonable certainty the expected returns on the investments.

These estimates require an understanding of

Photo: C. Hanchey/Flickr

The parallel I-25 bridges over Nogal Canyon in New Mexico were completed in 1968; they are on the Federal Highway Administration's list of Nationally and Exceptionally Significant Features of the Federal Interstate Highway System.

PHOTO: JAAN/FLICKR

Before 2004, vehicle miles traveled (VMT) grew faster than the expansion of Interstate lane miles; VMT per lane mile since has leveled off.

highway system characteristics and of the technologies in development to enhance highway safety and reliability. Some technical advances, such as the navigational systems on cars and trucks, require little interaction with the physical characteristics of the roadways, except for warning drivers about construction sites and accidents.

Other technological features on vehicles depend more on the physical condition of the highway infrastructure. For example, features installed on vehicles can warn the driver about inadvertent lane changes. These kinds of devices depend on well-defined lane markings. If the lane markings are nonexistent or have faded because of wear and neglect of the highway surface, the systems will fail, and the drivers who depend on the warnings will be placed in jeopardy.

Driverless cars—likely to be on the roads within the next decade—rely on a complex combination of sensors and computers to pilot through the confusing obstacles drivers confront every day. With the advent of these vehicles, state departments of transportation may have to change priorities from straightening curves to focusing on painted lane dividers to achieve safer roads.

New Priorities for Maintenance

Because many technologies rely on well-maintained highways, proper highway maintenance is paramount. According to a recent report from the International Transport Forum (ITF), "deferring maintenance can make roadway costs much greater than indicated by current expenditures" (*3*). The authors emphasize the long-term problems caused by deferring maintenance, such as the increased cost of restoring a road surface to acceptable conditions after long neglect.

The immediate problem is that many of the new and forthcoming technologies cannot operate optimally without proper maintenance. The authors of the ITF report conclude that proper attention to maintenance requires more detailed metrics for pavement conditions and for other physical conditions of highways.

Expanding the Scope of Benefits

In addition to collecting metrics that capture the physical characteristics of highways more accurately, an expanded understanding of the benefits generated by highways is necessary. Benefit–cost analyses typically focus on travel time, safety, and reliability. Recent research has expanded the scope of benefits to include several types of externalities, which are important in reflecting the full benefits of highway investment.

UK Framework

According to a report from Cambridge Systematics, the United Kingdom may be the furthest along in formulating a framework and in filling in the details of procedures and methods to make economic evaluation "a driving factor in transportation investment decisions" (*4*, p. 1).

The UK approach, developed by Sir Rod Eddington and known as the Eddington Report, attempts

Embedded data loggers are installed to assess concrete strength. The future highway will be a maze of technologies and signals on which intelligent vehicles will operate—investment decisions require accurate pricing and estimates on the returns.

Photo: Utah DOT

to identify and quantify wider benefits of transport investment than are captured in traditional benefit–cost analyses. The Eddington Report identifies seven microeconomic mechanisms that transport investments can influence, including externalities such as increased business efficiency through time savings and improved reliability for business travelers, freight, and logistic operations and the attraction of globally mobile activity through a thriving business environment and a good quality of life.

SHRP 2 Guidance

A report from the second Strategic Highway Research Program (SHRP 2) follows an approach similar to Eddington's by prescribing ways to include the wider benefits of externalities, environmental impacts, labor market efficiencies, and business efficiencies into standard benefit–cost analyses (*5*).

The SHRP 2 guide targets three classes of wider effects: reliability, intermodal connectivity, and market access. These benefits go beyond the traditional measures of traveler impact, which are based on average travel time and travel cost, and include factors that enable businesses to gain efficiency by reorganizing their operations, by opening access to a pool of talented workers, or by changing the mix of inputs to generate products or services.

The tools to incorporate these benefits within benefit–cost analyses draw on a searchable database of ex post evaluations of 100 projects across the country. Also included is an expert system that draws from the database to estimate the range of the likely economic impacts of any kind of project in any defined setting (*5*, p. 3).

Although an advance from the traditional benefit–cost approach, the SHRP 2 technique still falls short of the broader issues facing highway investment—namely, the interface with technology primarily emanating from the private sector.

Quantifying Benefits

How important are these wider benefits within a mature highway system? The system is so large that any investment—even a major investment—may not be large enough to make a difference in total travel time.

An example of lane-detection algorithm outputs; like many new technologies, lane detection requires proper road maintenance to work.

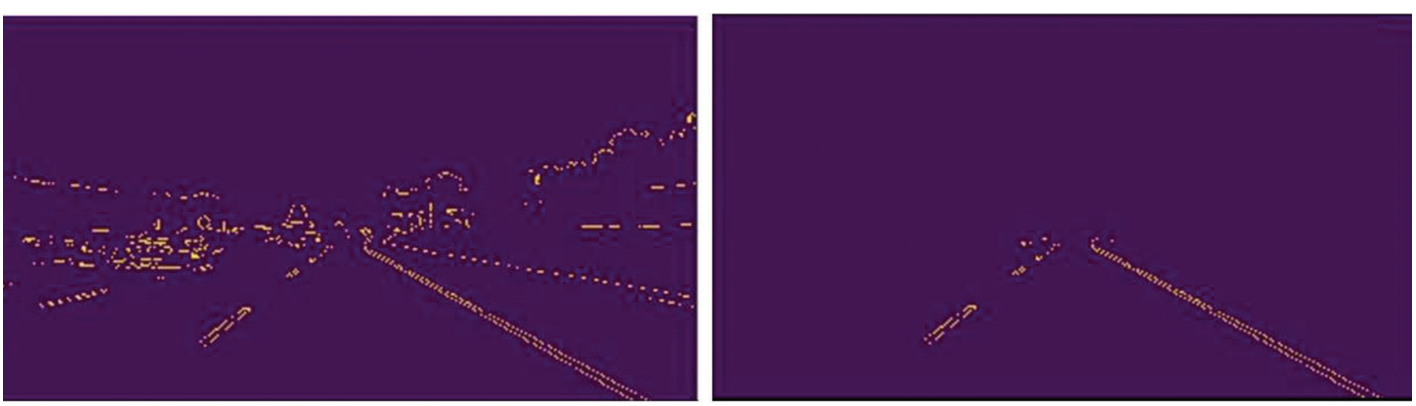

Image: Vidyak/Wikimedia Commons

Some markets with positive externalities, however, may be amenable to greater accessibility through transportation improvements. For those markets, transportation investment can reduce production costs, improve productivity, enable more efficient use of resources, and expand output. Many of these externalities depend on geography; this indicates the need to emphasize the broader benefits in state and local analyses of the value of highway infrastructure.

The benefits of a mature transportation system may be more difficult to quantify than those of a less developed system. In 2012, the panel for a National Cooperative Highway Research Program (NCHRP) project concluded that a mature highway system makes understanding the link between transportation services and economic outcomes much more difficult (*4*).

One reason is that transportation services, particularly within a mature system, are woven into the economic fabric of the nation, so that studying the effects of the services is difficult—and isolating the services from others that are closely interconnected is even more difficult. The NCHRP report raised the conceptual issue that limitations on available data hamper analyses of the causes and effects for actions that optimize service within a mature system—in contrast with a system that is expanding with completely new facilities (*4*, pp. 1–2).

Framework for the Next Stage

Nonetheless, the modular approach of SHRP 2 and the Eddington Report provides a framework for the next stage in estimating the value of highway infrastructure, by integrating new technologies into the traditional highway infrastructure and incorporating the wider benefits of highways into benefit–cost analyses. Many of these advanced technologies—such as collision aversion, navigational advances, and others in the driverless cars undergoing trials—are already in use, and researchers have identified and estimated the wider benefits.

Theory and changing economic conditions make clear that researchers will never find the one true estimate or Holy Grail of the value of highway investments. Instead, the search for methods to value the highway system with accuracy must start by developing appropriate evaluation methodologies for the realities of the present system.

All indicators confirm that the highway system is maturing. Investment decisions therefore require a keen understanding and monitoring of the physical characteristics of the system and of the broader perspective of the economic and societal benefits of highways.

Photo: Stella Pictures/Fairway Flyovers for Highways England

Catthorpe junction on the M1 near Leicestershire, England. In the United Kingdom, the evaluation of transportation assets identifies the microeconomic mechanisms that transportation investments can influence.

More advanced methodologies, such as that developed through SHRP 2, can help decision makers estimate the value of highway infrastructure within this new context. Nevertheless, these more advanced methodologies are only in their infancies, and more work is needed so that benefit–cost analyses take into account the increasing use of private-sector technology to enhance the safety and reliability of highways.

Highways are an integral part of the U.S. economy and of the nation's ability to compete globally—this role will only intensify. Appropriate and accurate evaluation tools must be available to public decision makers and to private businesses to ensure that the required investments are made to keep the nation's highway system viable today and into the future.

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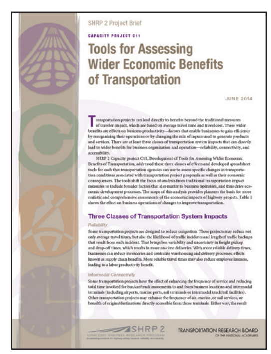

SHRP 2 Project Brief

CAPACITY PROJECT C11

Tools for Assessing Wider Economic Benefits of Transportation

JUNE 2014

Three Classes of Transportation System Impacts

SHRP 2

TRANSPORTATION RESEARCH BOARD

For more information on SHRP 2 Capacity Project C11: Development of Tools for Assessing Wider Economic Benefits of Transportation, see the project brief at www.trb.org/Main/Blurbs/170902.aspx.

PHOTO: CTA WEB/FLICKR

Transportation Investments in Response to Economic Downturns

Increasing the Effectiveness of Federal Stimulus Programs

JOSEPH MORRIS

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After the U.S. economy entered a severe recession in 2007, the federal government acted to reduce the costs of the recession and to speed recovery. One measure, the American Recovery and Reinvestment Act of 2009 (ARRA), provided \$831 billion in new spending and tax relief. The act appropriated \$48.1 billion to be administered by the U.S. Department of Transportation (DOT), mainly for grants to state and local governments for capital expenditures—\$27.5 billion for roads, \$8.4 billion for transit, \$9.3 billion for passenger rail, and \$2.9 billion for marine, aviation, and multimodal projects.

The rationale for spending on public infrastructure to aid in recovery from a recession is to provide funds that directly affect employment on construction projects and in the supplier industries; in turn, the construction and supply industry workers will spend their wages, which induces additional hiring. During recovery from a recession, as the economy moves toward full employment, the stimulus benefit of infrastructure spending—that is, the resulting increase in economywide employment—is weakened, because the directly employed workers and equipment largely are diverted from other employment.

Nevertheless, during a recession—as during normal times—infrastructure investment, apart from its stimulus effects, can produce benefits over many years through improved public services and increased productivity.

Learning from ARRA

ARRA provided a valuable case study of the man-

(*Above*:) Transit track workers in Chicago. Infrastructure improvements during the 2007 recession were facilitated by the American Recovery and Reinvestment Act of 2009 (ARRA).

agement and impact of a transportation stimulus spending program. The Transportation Research Board (TRB) formed a committee, sponsored by the National Cooperative Highway Research Program and by TRB, to examine the ARRA experience (see box, page 34). The committee's charge was to determine the value of transportation investments as a stimulus, as well as the structure and management of a transportation stimulus program that would produce the greatest benefit (*1*). The objective was to aid Congress and state and federal transportation administrators in planning any future stimulus program that may include transportation spending.

The experience of the ARRA transportation program has more than historical interest. Several times in past decades, the federal government has undertaken public works stimulus spending programs in response to recessions, but with mixed results. The U.S. economy at present is growing, and the unemployment rate is low; since World War II, however, recessions have occurred on average once every seven years—the most recent recession ended eight years ago. Sometime in the next few years, therefore, Congress is likely to consider measures to speed recovery from a recession.

The TRB committee did not assess the effect of transportation expenditures on employment or economic growth in the long term—that is, over several business cycles. This effect is distinct from that of transportation spending as a fiscal stimulus during a recession. The primary long-term contribution of transportation investment to the growth of income derives from the benefits of increased mobility for users of transportation facilities. These benefits can be evaluated through a benefit–cost analysis of transportation projects.

ARRA Precedents

A fiscal stimulus program is a package of extraordinary federal government expenditures or tax concessions funded by borrowing, with the goals of reducing the rate of unemployment, increasing employment, and speeding economic recovery. Most of the ARRA transportation provisions and earlier federal countercyclical public works programs fit this description.

Before ARRA, the federal government had undertaken public works stimulus spending in response to a recession on four occasions since World War II:

◆ The Public Works Acceleration Act of 1962, after the 1960–1961 recession, provided $852 million for local projects, administered by the Department of Commerce.

◆ Legislation in 1976 and 1977, after the 1973–1975 recession, provided $6 billion for the Local Public Works Program under the Economic Development Administration.

◆ The Emergency Jobs Appropriation Act of 1983, after the 1981–1982 recession, provided $7.8 billion for public works, including $900 million for programs administered by U.S. DOT.

◆ The Supplemental Appropriations Act of 1993 provided $100 million of public works funding—the Administration had asked for $6 billion—following the 1990–1991 recession.

In addition, in 1971, after the recession of 1969–1970, Congress passed a $2 billion Accelerated Public Works bill, vetoed by the President.

Critiques of Earlier Programs

These programs were small in comparison with the public works spending under ARRA, and none devoted as large a share of public works spending to transportation. Each program was enacted after the recession that apparently motivated it had ended.


Photo: Abbie Rowe, John F. Kennedy Presidential Library and Museum

President John F. Kennedy signs the Public Works Acceleration Act in September 1962.


Photo: Kristine Paulus/Flickr

The Bronx River Alliance received $10 million in ARRA funds for a 23-mile pedestrian and bike path along the length of the Bronx River. The project reclaims waterfront and develops green spaces for adjacent communities.

Expenditures on airports, highways, and dams under the Emergency Jobs Appropriations Act of 1983 were ineffective, according to a government report—the projects required too much time to develop and therefore could not jump-start the economy.

Photo: Prayitno/Flickr

The past public works stimulus programs were controversial. Opponents raised three objections:

◆ The time required to enact legislation and commence construction would make the spending too late to achieve the needed stimulus.

◆ State and local governments would substitute the federal funds for their own funds, reducing the net increase in spending.

◆ Rushing projects into construction would lead to a poor selection of projects.

Federal evaluations of the public works stimulus programs of the 1970s and 1980s concluded that the delays reduced the effectiveness of the spending as a stimulus and that new federal dollars tended to depress the spending of state and local government funds. The evaluations found that the information was insufficient to judge whether the funding had targeted the most worthwhile projects.

Construction in progress on Memorial Bridge between New Hampshire and Maine; safety issues had restricted traffic until a TIGER grant paved the way for reconstruction (see photo on next page).

Photo: Crystal Paradis/Flickr

Effectiveness of ARRA

The TRB committee concluded that these objections—although reasonable—were not as relevant for the ARRA transportation grants because of the economic circumstances and because of the act's administrative provisions for transportation spending. When ARRA was enacted in March 2009, the recession already had been under way for 15 months, but employment was declining and the recovery was slow; as a result, nearly all ARRA funds were spent during a period of high unemployment.

ARRA required transportation grant recipients to certify that they were maintaining planned rates of spending; this probably constrained the substitution of federal money for the grant recipients' own money—most state transportation spending depends on dedicated tax revenue not readily diverted to other purposes. The risk of poor project selection also was reduced, because most ARRA transportation funding flowed through the established federal highway and transit aid programs and went to projects already in state and local government plans.

Stimulus Advantages

The committee cited several advantages of including capital expenditures for transportation in a federal fiscal stimulus program:

◆ If projects are selected with care, the transportation benefits will offset the initial cost, justifying the expenditure, regardless of the magnitude of the stimulus benefit.

◆ A stimulus that accelerates planned expenditures adds less to the public debt than expenditures made without the need for a stimulus.

◆ Infrastructure improvement may raise consumers' and investors' expectations for long-term economic growth, magnifying the stimulus effect.

◆ Construction prices are likely to be lower during a recession, allowing transportation agencies to buy more with the funds available.

◆ When a recession strongly affects the construction industry—as in 2007 to 2009—infrastructure spending may be well-targeted as a stimulus.

In summary, the committee concluded that when the federal government decides to undertake stimulus spending, transportation grants are appropriate as a component of a diversified program, especially if a prolonged economic downturn is expected.

Increasing the Effectiveness

Although the transportation spending component of ARRA appears to have been appropriate and effective, state and local government grant recipients reported that certain rules of the program created administrative burdens and raised difficulties in compliance, as well as concerns about unintended consequences.

Most of the ARRA transportation funding flowed through established federal grant programs, but the act included special rules intended to enhance the stimulus impact. These included obligation and spending deadlines, along with requirements for maintenance of effort, spending in distressed areas, and collecting and reporting data.

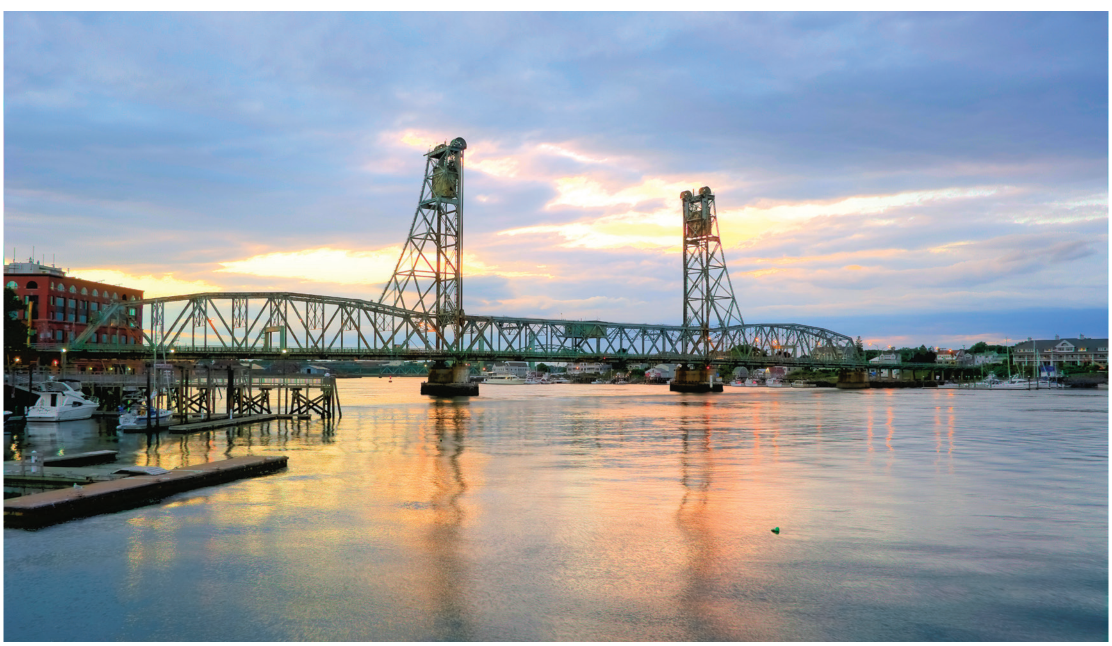
The TRB committee concluded that adjustments to the program's rules and administrative procedures could increase both the short-term stimulus benefit and the long-term mobility benefit from transportation spending in any future stimulus program. The committee recommended changes that would make established transportation funding programs more useful in counteracting economic downturns, including administrative provisions that could enhance the effectiveness of any future transportation stimulus program.

The committee recommended that Congress and

Photo: Adam Jones/Wikimedia

Low-income and distressed communities received priority ARRA funding.

Photo: Selbe Lynn/Flickr



The completed Memorial Bridge, funded through a TIGER grant, provides a multimodal link between Maine and New Hampshire (also see construction photo, page 32).

PHOTO: CENTER ATLANTA PROGRESS/FLICKR

The City of Atlanta submitted a four-phase, decade-plus proposal for funding the Atlanta Streetcar, a transit system that eventually will connect the downtown metro area to surrounding communities. Approximately half of the funding comes from TIGER grants; the rest is provided by the city, tax-allocation districts, and initiative programs.

the states consider adopting finance and administrative practices for established transportation funding programs that would allow state and local transportation agencies to maintain or increase spending in recessions and to absorb any future temporary federal assistance efficiently. This would benefit the economy by mitigating recessions, and the transportation system, by avoiding disruptions in construction schedules and by taking advantage of lower construction prices.

These actions would provide stability in the federal transportation funding programs; maintain a larger backlog of projects with completed designs and environmental reviews; and build balances in the transportation trust funds to sustain spending during recessions or to borrow against future user tax revenue to maintain spending when revenue slows.

Additional Refinements

The committee observed that uncertainty about the rules for the ARRA transportation program had slowed spending. The committee proposed, therefore, that Congress authorize U.S. DOT to publish rules on maintenance of effort, project eligibility, and data reporting for possible future application.

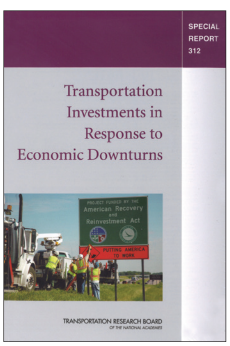
The committee recommended that any future transportation stimulus program should continue the ARRA practice of allocating most funds according to established formulas. This was critical to the timeliness of the ARRA spending.

The committee noted that the rate of spending in the new grant programs in ARRA—including the intercity passenger rail grants and the TIGER[1] competitive grant program—was much slower than that for ARRA funds in the established highway and transit programs. Therefore the committee recommended that timeliness requirements include multiple deadlines—a short deadline applicable to a portion of the funding and deadlines equivalent to those in the regular federal-aid programs for the remainder.

The committee found that some requirements in the ARRA transportation programs for collecting and reporting data had questionable usefulness for managing or evaluating the programs. The committee recommended that U.S. DOT review the requirements and specify data needs and methods for evaluating transportation stimulus spending.

Because the necessary data collection and evaluation procedures were not in place, the committee noted, the effect of the ARRA transportation grants on total state and local government transportation spending and on spending priorities could not be readily assessed. The committee recommended that U.S. DOT conduct research on how changes in the level of federal aid and in the rules of the federal-aid programs—notably for matching shares and for project eligibility—affect spending decisions by grant recipients.

[1] TIGER = Transportation Investment Generating Economic Recovery.



Special Report 312, *Transportation Investments in Response to Economic Downturns*, is available from the TRB Online Bookstore, www.mytrb.org/Store/Product.aspx?ID=5365. To view the book online, go to www.trb.org/Main/Blurbs/170114.aspx.

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Committee on Economic and Employment Benefits of Transportation Investments in Response to Economic Downturns

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Photo: U.S. DOT/Nick Roberts

From Preservation to Adaptation

Right Sizing as an Investment Strategy

CHANDLER DUNCAN AND ANNE MORRIS

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(*Above*:) The Big Four Bridge spanning the Ohio River in Louisville, Kentucky, was built for rail use in 1895. After falling into disuse in the 1960s, the approach spans were sold for scrap, earning it the nickname "The Bridge to Nowhere." The bridge reopened in 2013 for pedestrians and bicycles.

What happens when the economic value of a transportation facility or system diminishes because of a market shift? In a changing economy, how can an agency ensure that its portfolio of assets represents the most efficient mix of investments for moving people and goods? When should investments in life-cycle costs shift from current to new assets? What is the process for reducing or reusing overbuilt systems to ensure their ongoing value or to free up resources for emerging needs?

These are questions that agencies face in spending billions of dollars each year to preserve infrastructure assets. Understanding the right size of the current and future asset mix can reshape priorities, increase the return on investment for preservation, and transform the physical substance of the transportation system.

In the corporate world, right sizing often implies saving money by doing less, laying off workers, producing less, or cutting back when finances are insufficient. In the context of transportation infrastructure, however, right sizing signifies the integration of several long-standing concepts for a more efficient system.

The tactics draw from diverse transportation disciplines, including context-sensitive design, practical design, adaptive reuse, programmatic investment strategies, performance-based planning, asset management, risk-based planning, and value engineering. The combination creates a high-level paradigm for transportation decision making (see box, page 38). Right sizing stands as an alternative to the disinvestment that may occur when perceived needs exceed available revenues in a funding cycle.

Photo: Paul Krueger/Flickr

Right sizing addresses the needs of the community through context-sensitive designs such as planters and trees and with performance-enhancing features such as separated bike lanes.


PHOTO: MARC LAMKIN PHOTOS; TISE-KIESTER ARCHITECTS

A vacant 1935 manufacturing plant in Conover, North Carolina, was restored as a multimodal transportation center—a train station, bus station, library, and community center. The transformation of the building reinvigorated an aging part of town and provided needed transportation resources.

What Is Right Sizing?

All of the tactics cited can contribute to a right-sizing strategy. The primary economic objective is to direct agency resources to adapt the transportation system in the long term to a changing economy. Right sizing elevates the adaptation of the asset mix from an incidental opportunity—occasionally addressing a particular change in the economy—to make economic adaptation the central rationale for investment decisions.

Under a right-sizing strategy, decision making shifts the emphasis for investments consistently and deliberately from an asset-based goal of preservation or expansion that addresses condition and performance to a market-based goal that arranges and adapts assets in accordance with their role in the larger economy.


PHOTO: NPCA PHOTOS/FLICKR

Highway construction in Western states dried up after the housing crisis of the early 2000s; not long after, fracking in the Midwest created new communities in need of increased infrastructure.

Individual decisions can support right sizing in the following ways:

◆ Reducing or eliminating the capacity of assets that no longer serve markets, or

◆ Fundamentally altering the characteristics of assets from serving an obsolete purpose to serve a new and emerging purpose, and thereby

◆ Enabling a more economical use of resources in the long term, by saving life-cycle costs or by creating additional societal benefits.

An Emerging Perspective

In 2015, a National Cooperative Highway Research Program (NCHRP) synthesis project produced *Economic and Development Implications of Transportation Disinvestment*. The synthesis explored the problem of passive disinvestment, which occurs when the preservation of infrastructure does not meet the needs of users and therefore does not justify an expenditure of increasingly scarce resources (*1*).

Many previous studies lamented the nation's "crumbling infrastructure," but Synthesis 480 explored the hows and whys of disinvestment, recognizing the decisions agencies face and the need for agencies to recognize situations that can lead to a disinvestment. Often the return on investment from preserving assets in their current state does not measure up to the intended return envisioned when the assets were built.

When this occurs, agencies must choose between the inefficiency of preserving an asset that cannot be used fully or the inefficiency of losing all costs sunk in the asset. This dilemma leads to a larger discussion about keeping infrastructure investments current with the nation's changing transportation markets.

Reckoning with Change

In 1950, before the design and construction of the Interstate Highway System, only 64 percent of Americans lived in urban areas, compared with nearly 81 percent in 2010. During the housing crisis of the early 2000s, transportation agencies in some Western states abandoned plans for expanding highway facilities, because the forecasts of demand evaporated. In the same decade, oil-fracking technology precipitated the creation of new markets and new communities in North Dakota, Utah, Minnesota, and other states.

Emerging technologies, such as driverless and automated vehicles; "sharing" business models, such as those of Uber and Lyft; and the effects of climate change introduce more uncertainties into the question of what transportation assets the nation needs, and of how much of society's resources should be spent in developing and maintaining those assets.

Furthermore, connected and automated vehicles—along with the vehicle, fuel, and information technologies that are enhancing environmental and safety performance—can increase the performance of highways while using fewer lane miles of paved infrastructure. These developments will present opportunities for life-cycle cost savings through the streamlining of capacity, right-of-way, and asset portfolios to meet shifting economic needs and the constraints for the efficient use of infrastructure. A right-sizing investment model centered on economic adaptability may be the only viable, unifying approach to long-term investment strategies.

Expecting transportation agencies to preserve the national highway system as built in the mid–20th century is not realistic. Nevertheless, this has become a de facto goal for many agencies under the "fix it first" ethic that has accompanied asset management.

Photo: Peloton

Peloton tests out truck platooning technology that allows faster and more efficient driving. Connected and automated vehicles may reduce emissions and the need for additional paved infrastructure.

Decision Support

Although changes in transportation markets and needs are widely understood, the models for planning, asset management, and investment decision making are not integrated to assess the need or risk of spending on facilities. Passive disinvestment often is the result.

For example, the National Environmental Protection Act, federal transit programs, and grant programs such as TIGER and FASTLANE require significant benefit–cost and societal return-on-investment justifications for new projects.[1] Nevertheless, few agencies apply a similar rigor to investments in preserving facilities and rarely undertake an alternatives analysis or a corridor study to consider if an asset can be downsized, maintained with less costly methods, or transitioned to a different standard of capacity. Instead, the transportation investment process presumes the need to maintain assets as built but scrutinizes decisions that involve new capacity.

The challenge for agencies is that right-sizing opportunities often are hidden in a web of technical modeling and decision processes that prioritize expansion or the efficient preservation of the status quo. The right-sizing paradigm seeks to rework this web, respecting and utilizing the interconnected parts to reorient them for the most efficient use of current and future transportation resources.

Right sizing is possible because decision support systems and tools are more developed than ever before. Asset management systems, for example, have improved the tracking, prediction, and pricing of highway and bridge preservation needs. Demand forecasting models that once required rooms of computers monitored by doctoral-level programmers are now available on the desktops at many state departments of transportation.

Photo: Tennessee DOT/Flickr

Projects like this highway exchange in Tennessee must meet high return-on-investment and benefit–cost requirements to receive TIGER and FASTLANE funding.

[1] TIGER = Transportation Investment Generating Economic Recovery; FASTLANE = Fostering Advancements in Shipping and Transportation for the Long-term Achievement of National Efficiencies.

PHOTO: OREGON DOT/FLICKR

Paving along the I-5 corridor in Oregon. State agencies must decide which projects to maintain and which projects to adjust to changing needs.

Some states and metropolitan planning organizations deploy land use models that identify areas in which the type and intensity of development are most likely to change. Computer-aided design tools allow engineers to work and rework project designs to find the most practical and economical way to update or deliver a project.

Integrating Resources

Nevertheless, agency business processes are only beginning to integrate these resources into investment decision making or into a consistent understanding of needs and risks. Moreover, public involvement and outreach efforts are not prepared to engage community decision makers in considering the appropriateness of a smaller or less resource-intensive infrastructure footprint for a current facility.

Some transportation agencies, for example, declined to participate in the interviews for the NCHRP synthesis, concerned that the topic of disinvestment could raise political concerns. Furthermore, some practitioners noted that asset management systems can identify an agency's long-term investment needs from current trends and system conditions.

Others realized that an effective right-sizing paradigm, however, could go beyond building to meet current conditions or trends and to consider market uncertainty in managing the risk of over- or underbuilding. Assessing this type of risk requires identifying often overlooked ways to tie asset management systems to the models that agencies use for forecasting traffic.

Similarly, traffic forecasting models may benefit from right-sizing guidance to base ranges of traffic growth on possible levels of economic growth or on land use possibilities. In the same way, performance-based practical design initiatives have shown impressive results for stretching infrastructure dollars during a funding cycle. The right-sizing paradigm, however, seeks to offer step-by-step procedures to demonstrate how changing demand and market forces may alter the performance requirements for a facility.

Right-Sizing Criteria

◆ Reduce or eliminate outdated capacity or performance standards,

◆ Shift investment level and infrastructure footprint to reflect market changes, and

◆ Achieve long-term cost reduction or increase in societal benefits.

Right-Sizing Examples

Because right sizing is still emerging as a paradigm, no agencies have programs that can be studied. Nevertheless, the benefits of right-sizing strategies can be explored through examples that meet the criteria and that indicate the types of opportunities that systematically may be identified and pursued.

Big Four Bridge: Generating Benefits Again After More Than 30 Years

The Big Four railroad bridge in Louisville, Kentucky, meets right-sizing criteria. The original modal purpose was exchanged for a new value and use that generates livability, public health, and aesthetic benefits.

Built in 1895 across the Ohio River and updated in 1929, the bridge carried rail traffic for decades, as the city of Louisville grew and the regional economy changed, along with transportation demands, industry needs, and modal requirements. By 1969, rail access to the bridge was no longer necessary, and the bridge became a vestigial asset, nicknamed the "bridge that goes nowhere."

By the early 2000s, the bridge had become a problem—the long-term risk of collapse or deterioration and the cost of demolition and disposal were significant. In 2011, a joint effort by Kentucky and Indiana repurposed the bridge as a bicycle-and-pedestrian facility linking parks and walkways on both sides of the river.

The bridge has enabled Louisville and Jeffersonville, Indiana, as well as both states, to derive value from an asset that had ceased to serve its original purpose yet that offered potential for reuse, saving the costs of preventing deterioration or of deconstructing the bridge.

Although the Big Four Bridge obviously had not served its intended purpose for decades, the trans-

Photo: Louisville Images/Flickr

Decades after being abandoned, the Big Four Bridge now averages more than 1.5 million pedestrian and bicyclist visits per year.

portation agencies' planning, programming, asset management, and related processes had provided no way to bring the issue to the fore. Between 1969 and 2011, agencies committed resources to implement emerging new priorities without regard for the "bridge that goes nowhere."

The case raises questions about the business processes, analytical methods, and other tools available to agencies to identify assets when needs change—without waiting for decades—and to demonstrate the options and the societal return on investment for right sizing an asset.

Buford Highway: Less Speed, More Diversity

The need for right sizing Buford Highway, just outside of Atlanta, Georgia, was more subtle, and the stakeholder concerns were more complex, but the result has benefited the public. Although the original capacity of the highway remains unchanged, the project reduced the number of paved travel lanes in some areas and strategically compromised the intended performance characteristics of limited access, maximum automobile speed, and limited crossings.

The new portfolio of asset characteristics matches a shift in the residential, service, retail, and transportation economy of the area, and the changes are generating safety, livability, and aesthetic benefits in the long term.

Buford Highway serves as a major urban arterial both inside and outside of the Atlanta beltway. In the early to mid-1970s, the road was widened to seven lanes—six through lanes with a flush median—to accommodate traffic. The posted speed was 45 miles per hour, many intersections were more than 1 mile apart, overhead lighting was sparse, and sidewalks were sporadic—dirt, paved, or nonexistent. The population along the corridor was predominately white, middle income, and English speaking and had personal transportation.

In the next decade, the area experienced population growth and changes in demographics. An influx of Asians—including Koreans, Chinese, and Vietnamese—owned and operated businesses on the corridor but lived in residential areas off the corridor. In addition, predominately low-income Hispanics, who had limited access to personal transportation and depended on buses and carpools or on walking, moved in, continued to grow in number, and still live and work in the corridor.

By the early 2000s, the number of pedestrian-related fatalities and injuries on Buford Highway was increasing, and pedestrian safety became a major issue. The attributes associated with successful access management in the highway's original design—infrequent signalized intersections, limited overhead lighting, and a shortage of sidewalks—contributed to these problems.

Pedestrians were crossing Buford Highway at any point—the signalized intersections often were 1 mile or more away from key destinations. Pedestrians would risk injury or death by running across three lanes of traffic, stopping in the median, and

Photo: Transportation for America/Flickr

Pedestrians attempt to cross the seven-lane Buford Highway in Atlanta. The long distances between traffic lights had led to dangerous pedestrian crossings.

Although Buford Highway was designed for automobile traffic, its lack of sidewalks became an issue for a new group of residents who rely on walking and cycling.

Photo: Transportation for America/Flickr

then crossing the next three lanes. Buford Highway's hilly topography compromised sight distance, and the limited overhead lighting left many areas dark. The lack of continuous sidewalks relegated pedestrians to walking on the highway. County efforts to beautify the facility raised questions about prioritizing aesthetics over community safety.

The Georgia Department of Transportation (DOT) partnered with the county and provided funding to address Buford Highway's safety issues in conjunction with the county's beautification plan. The collaborative process involved an extensive public outreach to the various ethnic communities, along with iterations of design and planning alternatives to balance the needs for access, safety, and aesthetics.

The process revealed that the capacity, performance, and design requirements for the corridor are entirely different from those addressed in the original design of the 1970s. The phased repurposing of the corridor has included such features as paved sidewalks and overhead and pedestrian lighting on both sides, countdown signals at intersections, and signalized midblock crossings. The phased construction has been under way since the early 2000s, with the final phase scheduled for 2020.

More Efficient Paradigm

Buford Highway demonstrates the potential complexity of a right-sizing opportunity—identifying the need, proposing a new performance standard, and appropriately serving a diverse population. Local advocacy groups, the news media, and local government played a vital role in raising awareness of the changing needs in the corridor. As with the Big Four Bridge, the Buford Highway example points to the need for business processes, methods, and tools to enable agencies to identify, prioritize, and address systematically the changing needs and requirements of facilities.

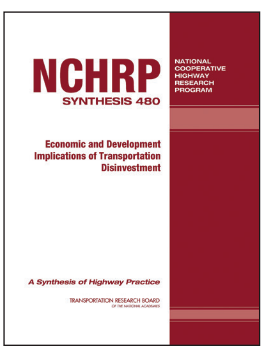
NCHRP has initiated a project to identify and recommend ways for transportation agencies to identify right-sizing opportunities, incorporate right-sizing scenarios for facilities into planning and programming, and anticipate and communicate the potential benefits from the projects.[2]

Right sizing has the potential to change the way that agencies identify needs, manage assets, and prioritize investments and to affect the size, shape, and function of the transportation system. At its best, right sizing can achieve a more efficient use of resources than any current paradigm of decision making, by critically evaluating and weighing the real economic efficiencies and societal returns, not only from new projects, but from all aspects of the transportation system.

Reference

1. Duncan, C., and G. Weisbrod. *NCHRP Synthesis 480: Economic and Development Implications of Transportation Disinvestment*. Transportation Research Board of the National Academies, Washington, D.C., 2015. www.trb.org/Main/Blurbs/172915.aspx.

[2] NCHRP Project 19-14, Right Sizing Transportation Investments: Methods for Planning and Programming, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4205.



More information about NCHRP Synthesis 480, *Economic and Development Implications of Transportation Disinvestment*, can be found at www.trb.org/Publications/Blurbs/172915.aspx.

OHIO DEPARTMENT OF TRANSPORTATION

Stream Channel Maintenance at Bridge Crossings in Ohio

Collaborative Approach Leads to Innovation and Implementation

JILL MARTINDALE

The author is District Research Coordinator, Ohio Department of Transportation, Columbus.

The Ohio Department of Transportation (DOT) has increased the involvement of districts and counties in the research process during the past five years. By soliciting ideas and encouraging collaboration between the central office, the districts, and the counties, Ohio DOT has solved significant problems effectively through research projects, often gaining a large return on the investments.

In addition to the cost savings, collaborative research projects often have improved morale and a sense of job ownership among participants. Collaboration between Ohio DOT and a multidisciplinary research team was a key to the success of a research project on alternative stream channel maintenance at bridge crossings (*1*).

Problem

Streams are dynamic. Natural processes, such as bank erosion and sediment deposition, are necessary for a healthy stream system. The movements and adjustments of streams, however, often create problems at crossings with bridge structures, which must remain in a fixed location. Typical problems at bridge crossings include the following:

PHOTO: RICHARD W. SHATZER, OHIO DOT

Stream vanes constructed of precast concrete block at the SR-20 bridge over Bean Creek in Fulton County, Ohio.

◆ Deposition of sediment upstream of a bridge—this can misalign the flow through the opening and can affect the conveyance capacity of the structure;

◆ Incision of the channel, which can expose the foundations of the abutments and piers; and

◆ Lateral migration of the stream banks, which can lead to erosion.

Throughout the state, crews from Ohio DOT counties routinely maintain stream channels to minimize the impact of stream dynamics on bridges. Generally, district and county crews have relied on labor-intensive practices to remove debris jams, to dredge the sediments that have accumulated at bridge openings, and to armor stream banks and the structural components of bridges that are affected by erosion.

These measures are rarely sustainable, however, and many require frequent and costly maintenance that can become a burden to county forces and can lead to allowable, but repeated, impacts on the environment. Ohio DOT sought solutions from the stream engineering community—such as natural channel design practices, as well as tools—to assist district staff and county crews in solving maintenance issues.

Solution

Ohio DOT worked with the research team to accomplish the following:

◆ Assess the skills of county maintenance forces,

◆ Inventory the construction equipment available to county crews, and

◆ Evaluate the accessibility of specialized construction materials.

With this information, the research team identified a viable subset of the stream channel maintenance practices described in Federal Highway Administration manuals (*2*) and in the peer-reviewed literature (*3, 4*). The researchers discussed potential solutions with Ohio DOT staff and together selected

FIGURE 1 Examples of natural channel design practices explored by Ohio DOT researchers (*clockwise from top left*): single-arm vane, cross vane, W-weir, and two-stage channel.

specific practices and construction materials for field testing. The team developed preliminary designs for nine project sites; through an iterative process, Ohio DOT and the research team refined the proposals.

The selected practices included single-arm vanes, cross vanes, W-weirs, and two-stage channels—all common in stream restoration. The team made minor modifications to adapt the practices for installation near bridges. Tests on alternative construction materials included tied concrete matting, concrete cloth for slope stabilization, and concrete blocks as a substitute for the irregularly shaped quarried limestone boulders typically used in vane structures.

Application

Pilot projects were implemented at eight sites in Ohio DOT Districts 2 and 3. Five sites received vane structures; one site implemented the two-stage channel design; and five of the sites used slope stabilization and new construction materials.

The implementation in Wayne County on State Route 83 at Savage Run provides an example of the success. The deposition of sediment at the site had partly blocked the bridge opening and had misaligned the stream flow, causing erosion at the upstream wing wall—that is, the retaining wall next to the abutment. The poor alignment also caused sediment deposition downstream of the bridge, and this was affecting the conveyance capacity of the opening.

Multiple attempts to protect the abutments included riprap and grouted riprap, but additional maintenance was still necessary. Ohio DOT staff and the research team decided on a single-arm vane structure to guide the flow away from the eroding embankment, to align with the bridge opening.

Ohio DOT staff suggested constructing the vane with large concrete blocks, which are cheaper, readily available, and structurally superior to the quarried limestone blocks typically used. The work was completed in three days, and after two years, the vane continues to meet the objectives of the project.

Benefits

The collaboration between Ohio DOT and the research team led to improvements on many projects and promoted acceptance of unfamiliar maintenance practices and of new construction materials. Actual project costs were less than originally estimated—for example, by approximately 75 percent on two of the vane projects. This was attributable to the use of innovative construction materials, the purposeful avoidance of challenging conditions—such as high stream flows—and the high level of skill and dedication of the county maintenance crews that implemented the projects.

In addition to the welcome cost savings, the most significant benefit from this project was the collaboration—not only between the central office, the districts, and the counties but between the environmental, hydraulics, structures, and other offices. County forces have recommended that the department be proactive in the design of bridges; this led to a joint meeting of the department administrators from environmental, hydraulics, and structures to determine how to move forward with what would be a major cultural change.

This project demonstrated the agency's guiding concept of one DOT—research determined the funding and the direction, the districts and counties defined the problems, and all of the agency worked together to create and implement the solutions. Stream Channel Maintenance at Bridge Crossings is one of several projects that have taken this collaborative approach to problem solving through research.

For more information, contact Jill Martindale, Ohio DOT, 1980 West Broad Street, Columbus, Ohio 43223, Jacquelin.martindale@dot.ohio.gov.

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1. Witter, J., D. Mecklenburg, M. Hebert, H. Yaryan-Hall, and P. Johnson. *Alternative Stream Channel Maintenance at Bridge Crossings.* Final research project report, Ohio Department of Transportation, Columbus, 2017.
2. *Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance*, 3rd ed., Vol. 2. Hydraulic Engineering Circular No. 23, Federal Highway Administration, 2009.
3. Johnson, P. A., S. A. Sheeder, and J. T. Newlin. Waterway Transitions at U.S. Bridges. *Water and Environment Journal*, Vol. 24, pp. 274–281, 2010.
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EDITOR'S NOTE: Appreciation is expressed to Stephen Maher, Transportation Research Board, for his efforts in developing this article.

Suggestions for Research Pays Off topics are welcome. Contact Stephen Maher, Transportation Research Board, Keck 486, 500 Fifth Street, NW, Washington, DC 20001; 202-334-2955; smaher@nas.edu.

CALENDAR

TRB Meetings

July

6–7 3rd International Symposium on Transportation Soil Engineering in Cold Regions
Guide, Qinghai, China

11–13 Automated Vehicles Symposium*
San Francisco, California

15–19 GeoMEast International Conference: Innovative Infrastructure Geotechnology*
Sharm El-Sheikh, Egypt

16–18 International Bridge, Tunnel, and Turnpike Association–TRB Joint Symposium on Managed Lanes and All-Electronic Tolling*
Dallas, Texas

18–21 Summer Conference of the TRB Resource Conservation and Recovery Committee
Duluth, Minnesota

19–21 Maintenance and Rehabilitation of Constructed Infrastructure Facilities*
Seoul, South Korea

23–26 Transportation-Related Noise and Vibration Committee Summer Conference
Minneapolis, Minnesota

24-26 22nd International Symposium on Transportation and Traffic Theory*
Evanston, Illinois

27–28 8th International Visualization in Transportation Symposium: Visualization in Action
Washington, D.C.

30–Aug. 2 56th Annual Workshop on Transportation Law
Salt Lake City, Utah

TBD Historic and Archeological Preservation in Transportation Committee Summer Conference
Minneapolis, Minnesota

August

21–22 9th New York City Bridge Conference*
New York, New York

22–25 16th Biennial Asilomar Conference on Transportation and Energy*
Pacific Grove, California

27 American Society of Civil Engineers International Conference on Highway and Airfield Technology
Philadelphia, Pennsylvania

September

6–8 Transit Geographic Information Systems Conference*
Washington, D.C.

11–13 2nd TRB Conference on Transportation Needs of National Parks and Public Lands: Partnerships for Enhancing Stewardship and Mobility
Washington, D.C.

26–27 11th University Transportation Centers Spotlight Conference: Rebuilding and Retrofitting the Transportation Infrastructure
Washington, D.C.

26–28 1st International Intelligent Construction Group Conference*
Minneapolis, Minnesota

October

6 10th SHRP 2 Safety Data Symposium: From Analysis to Results
Washington, D.C.

15–19 American Concrete Institute Fall Convention
Anaheim, California

29–Nov. 2 Intelligent Transportation Systems World Congress
Montreal, Quebec, Canada

November

6–9 6th International Human Factors Rail Conference*
London, United Kingdom

12–15 2nd Pan American Conference on Unsaturated Soils*
Dallas, Texas

14–16 Applying Census Data for Transportation
Kansas City, Missouri

14–16 29th Road Profile Users Group Conference*
Denver, Colorado

December

7–8 National Accelerated Bridge Construction Conference*
Miami, Florida

17–20 4th Conference of the Transportation Research Group of India*
Mumbai, India

January

7–11 TRB 97th Annual Meeting
Washington, D.C.

Additional information on TRB meetings, including calls for abstracts, meeting registration, and hotel reservations, is available at www.TRB.org/calendar, or e-mail TRBMeetings@nas.edu.

*TRB is cosponsor of the meeting.

George Avery Grimes

Patriot Rail Company

With more than 40 years of experience in the rail industry, from organizational transformation and investment analysis to marketing and environmental management, George Avery Grimes guides the work of the Transportation Research Board's Rail Group and its eight standing committees. Grimes joined the Standing Committee on Freight Rail Transportation in 2007, serving as a major organizer of the Joint Rail Conference on High-Speed Rail and Intercity Passenger Rail in 2010 and as chair of the committee from 2011 to 2017, reshaping the committee's direction and developing a new mission statement. He also served on the Standing Committee on Critical Transportation Infrastructure Protection from 2002 to 2005.

Grimes is senior adviser to the CEO of Patriot Rail, a privately held shortline holding company; he previously served as Executive Vice President and Chief Strategy Officer, responsible for the acquisition of railroads and rail-related facilities and for the integration of strategic business issues. He guided efforts to redevelop and professionalize Patriot Rail's business practices and policies, from marketing to operations, and was instrumental in finding and securing interest from the infrastructure investment firm that acquired Patriot Rail properties in 2012. Grimes also serves as chair of Union Pacific's Shortline Advisory Group and as a member of BNSF's Shortline Caucus.

"No matter how technical your field of interest is, your ability to succeed still comes down to your ability to communicate with and influence people."

"Ongoing research is fundamental to improving rail safety and productivity—both of which are essential to a growing and vibrant industry," Grimes observes.

Before joining Patriot Rail in 2012, Grimes held leadership positions at a variety of rail organizations, guiding corporate transformations and major projects. As senior adviser to the CEO at Metra, Chicago's commuter rail system, he deployed management assessment and best practices, organizational structure, leadership strategy, critical risk analysis, metrics development, and fare and funding analysis to transform the company. He also served as deputy CEO at Southern California Regional Rail Authority–Metrolink from 2010 to 2011, supporting a new CEO on a major corporate turnaround that included organizational restructuring, internal audit, engineering and capital projects, and more. Before that, he served on the Technical Advisory Team at Macquarie Group for the Denver Eagle P3 commuter rail project—a multibillion-dollar public–private partnership in Colorado—and advised private equity funds on the financial viability of, and strategies for, freight rail investments.

Other roles include senior vice president of strategic planning and business development at OmniTRAX, a shortline railroad company, from 2007 to 2009; assistant vice president of business development at Kansas City Southern; and partner at the Center for Toxicology and Environmental Health.

"No matter how technical your field of interest is, your ability to succeed still comes down to your ability to communicate with and influence people," Grimes notes.

From 1978 to 1995, Grimes worked for the Union Pacific and Missouri Pacific Railroads, at director-level positions in engineering, environmental operations, transportation, and finance. He developed financial, safety, transportation and operating performance systems and metrics; directed emergency response and environmental operations efforts after major derailments and toxic chemical releases; guided the financial management of engineering projects, service agreements, and more; and created new techniques for train system design, safety and accident analysis, and risk management. Grimes also has been a licensed locomotive engineer and has operated locomotives in through and switch service.

"Spend some of your development time with people in the trenches doing the physical work—you have a lot to learn from them," he observes.

Grimes received a bachelor's degree in railroad civil engineering from the University of Illinois at Urbana–Champaign (UIUC) in 1978 and a master's degree in civil environmental engineering from the University of Nebraska in 1994. He served as adjunct faculty at the University of Denver Intermodal Transportation Institute from 1999 to 2001, teaching economics, human factors, and research methods. In 2004, Grimes completed his PhD at UIUC in engineering, economics, and finance. In his dissertation on the nature of railway investment, he first demonstrated that regulatory formulas underestimate variable capital costs and then developed a new profit-maximization theory for freight railroads based on the concept of variable capital costs.

"Never, ever stop learning and always ask questions," Grimes notes. "Our world is constantly changing and you must stay ahead of the curve."

Barbara A. Ivanov

University of Washington

Barbara A. Ivanov promotes and facilitates practical research results, both as Director of the Urban Freight Lab at the University of Washington (UW) and as Chief Operating Officer of the Supply Chain, Transportation, and Logistics Center (SCTL).

"The most interesting research solves real-world problems," Ivanov comments. "To work with industry, we need to start by asking them for key problems in the public–private transportation space, and then designing research plans around their unmet needs." SCTL integrates education, research, and in-depth consultation with key players to improve public freight systems for business sectors, supply chains, and surrounding communities. A partnership between the Seattle Department of Transportation (DOT) and the private sector, the Urban Freight Lab is a "living laboratory" that tackles delivery systems challenges in urban areas.

"Being open about failure is as important as objectivity when reporting results."

The Urban Freight Lab's first research project examines the "final 50 feet" of the urban delivery system—the last leg of the delivery process, which begins when a truck stops at the customer's location and ends with physical receipt of the goods. Ivanov facilitates the lab's research projects, maintains its financial stability, delivers data-based results, manages real-world pilot tests, and communicates research outcomes.

Ivanov's expertise includes developing data-based decision support to improve capital investment in and management of public freight infrastructure, as well as helping diverse groups identify priority needs, develop solutions, and deliver on common goals. She has worked with U.S. DOT, the Federal Highway Administration (FHWA), the second Strategic Highway Research Program (SHRP 2), and the Transportation Research Board (TRB) to develop freight performance metrics, performance-tracking systems capabilities, and economic impact analyses; to implement advanced collection methods and analytic tools for freight data; and to advocate for resilient freight systems. Ivanov has led peer exchanges on such topics as cooperative multiagency freight planning at the state and regional levels and has coordinated state input into the National Freight Network and the National Freight Strategic Plan. She also has conducted FHWA webinars on such topics as freight system resiliency and land use–based freight planning.

"Not every research project results in a best practice, as you may believe if you attend too many conferences. In fact, most do—and should—produce failures; it's the only way we can learn," Ivanov observes. "Being open about failure is as important as objectivity when reporting results."

Current research topics include reducing truck dwell time and failed first deliveries of goods in urban systems; improving the productivity of truck loading and unloading spaces in cities and of truck parking along major corridors; and developing a database-enabled trust framework to enhance operational security of global supply chains, logistics, and smart goods and the Internet of things.

Ivanov received both a bachelor's degree in English and a master's degree in business administration from the University of Washington. She also is a graduate of the U.S. Chamber of Commerce Institute for Organizational Management. She served as Assistant Director and then Executive Director of the Kent, Washington, Chamber of Commerce; in 2003, she joined Washington State DOT as Director of the Freight Systems Division. At Washington State DOT, she led many noteworthy efforts—an agencywide economic impact analysis for passenger and freight transportation investments; the online Freight Alert and Commercial Vehicle Pass System; low-cost, high-value resiliency solutions for major freight system disruptions; and the Washington State Freight Mobility Plan. The freight plan won several communications awards: TRB's 8th Annual Communicating Concepts with John and Jane Q. Public Competition, the AVA Digital Award, the Communicator Award, and the MarCom Award.

"I encourage young women in research to sit down at the big table and lay out their best ideas," Ivanov notes.

Ivanov joined TRB in 2007 as a member of the Hazardous Materials Cooperative Research Program's Hazardous Materials Commodity Flow Data and Analysis project panel. She has served on several project panels for the Cooperative Research Programs and SHRP 2, including a National Cooperative Freight Research Program panel on Understanding and Using New Truck Data Sources to Address Urban Freight. She chaired the Standing Committee on Intermodal Freight Transport from 2008 to 2013 and then the Freight Group from 2013 to 2016.

As Freight Group chair, Ivanov guided the work of 12 freight committees and represented the committees' interests on the Technical Activities Council. She also chaired the Subcommittee on the Transport of Energy Products and is a member of the Standing Committee on Urban Freight Transportation, coordinating the Freight Day activities and other sessions for the 2018 TRB Annual Meeting.

Making a Pitch for Innovations

ALEX BIGAZZI

The author is Assistant Professor, Department of Civil Engineering and School of Community and Regional Planning, University of British Columbia, Vancouver, Canada.

Entrepreneurs pitched transportation technology ideas to transportation industry investors and business leaders—and a standing room–only crowd—at the Six-Minute Pitch Start-Up Challenge during the Transportation Research Board (TRB) 2017 Annual Meeting in Washington, D.C. A panel of judges—Jessica Robinson of Ford Smart Mobility, Emily Castor of Lyft, David Zipper of 1776, and Chris Thomas of Fontinalis Partners—evaluated the proposals for commercial feasibility and effectiveness in meeting critical transportation challenges and in implementing transportation research and offered advice to the business owners.

The winner of the Six-Minute Pitch was InspectX, a bridge inspection app from the software company Bridge Intelligence. Cofounder and managing director Hooman Parvardeh commented that observing outdated, inefficient bridge inspection practices motivated him to create an app to improve accuracy and efficiency. Acting on the judges' advice, Parvardeh has expanded the company's target market to include consulting firms; he also is refining product offerings and developing marketing activities.

According to Parvardeh, the validation of the InspectX business model was particularly helpful. "The feedback that we received from the judges was invaluable," he noted.

The session was sponsored by the TRB Young Members Council and moderated by Shana Johnson of Foursquare Integrated Transportation Planning, Susan Paulus of Lakeside Engineers, Robert Rodden of PNA Construction Technologies, and the author. The winner also received a one-year membership in the 1776 Union, a global platform for entrepreneurs and start-ups.

For details on the Six-Minute Pitch and to start planning a pitch for 2018, please visit sixminutepitch.com.

PHOTO: SHANA JOHNSON

(*Left to right*) Six-Minute Pitch judges Chris Thomas and Emily Castor, contest winner Hooman Parvardeh, and judges David Zipper and Jessica Robinson.

PHOTO: SHANA JOHNSON

Hooman Parvardeh (*far right*) makes his winning pitch for start-up funding for the bridge inspection app InspectX during the TRB Annual meeting in January.

How to Talk About Transportation and Public Health

10th Annual TRB Contest Identifies Best Practices

TERRI H. PARKER

The author is Director, Marketing and Communications, Texas A&M Transportation Institute, College Station.

With outreach strategies ranging from pop-up traffic demonstrations to children's books, the winners of the 10th annual Communicating Concepts to John and Jane Q. Public competition illustrated the connection between transportation and public health.

Trailnet from St. Louis, Missouri, received top honors for the entry, Taking It to the Street: Traffic-Calming Pop-Up Demonstrations as a Planning and Public Health Tool. The Missouri Chapter of the American Planning Association collaborated with Trailnet, the Healthy Eating Active Living Partnership, the City of St. Louis, and community residents to address fatal traffic crashes involving pedestrians.

Pop-up traffic calming demonstrations in four St. Louis neighborhoods displayed proven methods to slow traffic and increase safety. The demonstrations taught residents, elected officials, and city staff how to create safer, healthier, and more vibrant communities. Traffic calming measures implemented in the wake of the pop-up demonstrations have included crosswalk enhancements near an elementary school, a mural at an intersection, and a beautification project.

Also receiving honors was the Northwest Air Quality Communicators' activity book, *Nora and Wes: Our Quest for Clean Air.* Originally drafted on a napkin, the book identifies air pollution problems and solutions with coloring and educational activities for children in kindergarten through third grade. The publication is available free of charge online; a follow-up graphic novel for students in fourth through sixth grades offers age-appropriate material to help children learn about air pollution challenges in the Pacific Northwest.

The Clear the Air Challenge, a traffic demand management initiative from TravelWise, a Utah DOT program, and other partners, also collected a runner-up prize. The annual, month-long challenge encourages participants—individuals, teams, and employers—to reduce vehicle emissions by choosing alternatives to driving alone. Now in its seventh year, the Clear the Air Challenge is one of the most recognized air quality initiatives in Utah. The program has helped eliminate more than 900,000 vehicle trips and 4,200 tons of greenhouse gas emissions.

The infographic Living Near Busy Roads or Traffic Pollution received an honorable mention. Submitted by the Southern California Environmental Health Sciences Center and Children's Environmental Health Center at the University of Southern California, the graphic communicates how various modes of transportation create pollution and how pollution affects individual health.

For more information on these entries and details on how to submit an entry for the 2017–2018 competition, visit the website for the TRB Committee on Public Involvement at http://sites.google.com/site/trbcommitteeada60.

Photo courtesy Terri Parker

A traffic calming demonstration program developed by Trailnet in St. Louis, Missouri, won top honors at the 10th annual Communicating Concepts to John and Jane Q. Public competition.

PHOTO: ALBAKKER, FLICKR

Traffic congestion—above, around Seattle—delays delivery of goods, creating higher company costs, which are passed on to consumers.

Congestion Clogs Trucking Revenue

Commercial truckers last year lost 996 million hours of productivity because of traffic congestion—the equivalent of 362,000 drivers sitting still for an entire year—according to a report from the American Transportation Research Institute.

Traffic congestion on the U.S. national highway system cost the trucking industry $63.4 billion in additional operating expenditures in 2015, a nearly 27 percent increase from the previous year, according to findings in the report. Poor infrastructure, extreme weather, and a substantial increase in traffic accidents exacerbated already clogged highways, raising costs for trucking companies in driver downtime and in the nondelivery or late delivery of goods.

Although only 17 percent of the national highway system generated 88 percent of congestion costs, most states face challenges. Bottlenecks near major metropolitan areas continue to demand attention, and the report cites the need for more research on the growth in e-commerce and on rural roads not designed for freight trucks.

For more information and to request the full report, visit http://atri-online.org/2017/05/16/trucking-industry-congestion-costs-top-63-4-billion.

Injuries and Costs Rise After Helmet Law Repeal

In Michigan, fewer motorcycle riders involved in crashes are wearing a helmet, and serious head injuries have increased by 14 percent after the state's partial repeal of its universal helmet law (UHL) in 2012.

A team of researchers from the University of Michigan Injury Center, the University of Michigan Transportation Research Institute, and the Insurance Institute for Highway Safety has released a study comparing statewide rates of helmet use, head injuries, and fatalities for the years before and after Michigan's partial UHL repeal.

The study revealed that helmet use declined by 24 to 27 percent among those involved in crashes and that the types of head injuries changed. Mild concussions decreased by 17 percent in the year after the repeal, but skull fractures increased by 38 percent.

The increase in serious head injuries is associated with an increase in more costly and invasive medical procedures, and researchers found that hospital service costs were 35 percent higher for unhelmeted than for helmeted crash victims. The average $33,000 cost for a motorcycle crash victim affects private insurance—claims are up 22 percent compared with totals from neighboring states—as well as safety-net programs.

This is the first study to examine data statewide in Michigan since the UHL repeal, and researchers express hope that the findings will help inform the policy debate on helmet use.

For more information, visit http://ajph.aphapublications.org/doi/full/10.2105/AJPH.2016.303525.

PHOTO: ELVERT BARNES, FLICKR

Since the universal helmet law was partially repealed in Michigan, serious head injuries and associated costs have increased dramatically.

Slower Driving Improves Urban Safety

Compiling research from around the globe, transportation experts at the World Resources Institute evaluated the effects of reducing car speeds on crash outcomes, road congestion, health, and the vibrancy of businesses on busy streets. In each case, studies showed the benefits of slower speeds.

As a driver's speed increases, reaction and braking time increase, and depth perception decreases. As a result, pedestrians and cyclists are not easily seen. Studies show not only that slower speeds greatly reduce the number of collisions with pedes-

Photo: Ricky Thakrar, Flickr

Roads that encourage pedestrian and bicycle traffic, such as Yonge Street in Toronto, are safer and thrive economically.

trians and cyclists, but that the likelihood of a fatality in a crash decreases from 85 percent to 10 percent when car speeds decrease from 50 mph to 30 mph.

With roads designed to encourage pedestrian and bicycle traffic and safer automobile speeds, more people choose to take fewer trips by car and opt instead for travel by foot or bike, reducing the risk of traffic collisions and decreasing harmful emissions. In addition, the exercise benefits for pedestrians and cyclists decrease health costs.

Studies in the United States and England also show that the slowing of traffic through retail and housing areas increased retail and service spending, as well as real estate value.

According to researchers from France and Brazil, slower car speeds not only save lives, foster healthier communities, and boost the economy but also ease congestion by as much as 10 percent, relieve bottlenecks, and add little to total travel time.

To read the article and see links to further research, visit http://www.wri.org/blog/2017/05/need-safe-speed-4-surprising-ways-slower-driving-creates-better-cities.

Commuter Program Grows Near Desert

Club Ride Commuter Services, a free ecofriendly program of the Regional Transportation Commission of Southern Nevada, registered nearly 10,000 new members in 2016 who commute by carpooling, walking, bicycling, motorcycling, transit, telecommuting, and working a compressed weekly schedule.

In the past year, members saved nearly $2.25 million on vehicle costs such as fuel and maintenance, an 18.4 percent increase over the previous year. The program also eliminated 7.2 million vehicles miles from Nevada roadways, up from 6.9 million miles in 2015.

According to the report, Club Ride commuters have contributed to the reduction of more than 142 tons of carbon monoxide and 5,800 tons of greenhouse gases in the past two years.

To see the full report, visit http://www.rtcsnv.com/wp-content/uploads/2017/03/RTC's-Club-Ride-program-marks-another-record-year-in-2016.pdf.

Bicycling Brings Economic Benefits

The health benefits associated with bicycling are well-proved, but a recent Minnesota study reveals a significant economic benefit.

The study by the University of Minnesota with funding from the Minnesota Department of Transportation found that in 2014, the bicycling industry in the state generated $778 million in economic activity. Of that total, 80 percent came from manufacturing and wholesale business, including 5,519 jobs, but bicycle events such as trail rides, races, and bicycle tours generated an additional $14.3 million in economic activity.

Bicycle commuting also notably lowers the risks of many life-threatening diseases, and researchers estimate that cycling extends the life span of 12 to 61 persons per year in Minnesota, saving $100 million to $500 million annually.

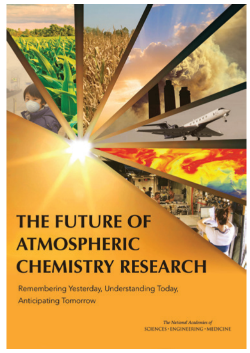
With as many as 96 million bicycle trips made annually for commuting, recreation, and other purposes, bicycling infrastructure is gaining importance in the state's multimodal transportation system.

For more information, visit http://www.dot.state.mn.us/bike/research/economic-health-impact.html.

Photo: FreewheelinBiker/Andy King, Flickr

Minneapolis mayor R. T. Rybak leads 150 cyclists through the city. Bicycle communities and activities bring economic benefits to cities.

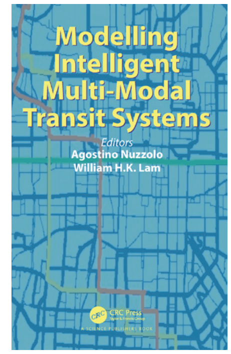
The Future of Atmospheric Chemistry Research: Remembering Yesterday, Understanding Today, Anticipating Tomorrow
National Academies of Sciences, Engineering, and Medicine; Division on Earth and Life Studies; Board on Atmospheric Sciences and Climate. National Academies Press, 2016; 226 pp.; $58; 978-0-309-44565-8.



This volume summarizes reasons to support a comprehensive U.S. research program in atmospheric chemistry; comments on the broad trends in laboratory, field, satellite, and modeling studies; determines priority research areas; and identifies the highest-priority improvements in the research infrastructure to address these topics.

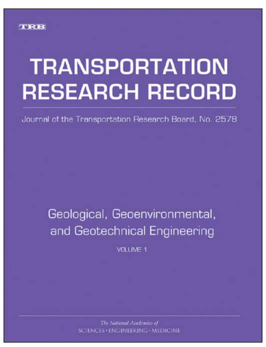
The titles in this section are not TRB publications. To order, contact the publisher listed.

Modelling Intelligent Multimodal Transit Systems
Agostino Nuzzolo and William H. K. Lam. CRC Press, 2016; 338 pp.; $269.95; 978-1-498-74353-2.



Integrated information and communication technology support tools are required for an effective intelligent, multimodal transit system. This volume examines the current trends in this emerging area.

TRB PUBLICATIONS



Geological, Geoenvironmental, and Geotechnical Engineering, Volumes 1–3
Transportation Research Records 2578–2580

These three volumes provide data and analysis of various types of asphalt, cement, pavement, and soil processes and maintenance, as well as the effects on and interactions with various environments.

2016; Vol. 1: 112 pp.; TRB affiliates, $53.25; nonaffiliates, $71; Vol. 2: 104 pp.; TRB affiliates, $49.50; nonaffiliates, $66; Vol. 3: 96 pp.; TRB affiliates, $49.50; nonaffiliates, $66. Subscriber categories: Vols. 1, 3: geotechnology, materials, pavements; Vol. 2: geotechnology, bridges and other structures, materials.

Developing Countries
Transportation Research Record 2581

Nineteen papers addressing issues in developing countries are gathered in this volume, including mode choice of low-income commuters, future travel demand in China, bus financing in Mexico, jitney network mapping in Ghana, and the waiting endurance time of pedestrians.

2016; 184 pp.; TRB affiliates, $60.75; nonaffiliates, $81. Subscriber categories: general transportation, safety and human factors, pedestrians and bicyclists.

Safety Management, School Transportation, and Safety Workforce Development
Transportation Research Record 2582

This volume explores transportation safety topics: distracted driving; safety management tools used in the United States, Canada, Switzerland, and Australia; and the perceived dangers of traveling to and from school.

2016; 104 pp.; TRB affiliates, $45.75; nonaffiliates, $61. Subscriber category: safety and human factors.

Statistical Methods and Highway Safety Performance
Transportation Research Record 2583

Crash rate models for a mountainous highway, safety impacts of rumble strip installation, the effectiveness of converting two-lane roadways into four-lane divided roads, and intersection conflict warning systems are a few of the subjects covered in this volume.

2016; 152 pp.; TRB affiliates, $60.75; nonaffiliates, $81. Subscriber categories: safety and human factors, data and information technology.

Operator Education and Regulations; Safe Mobility for Older Persons; Traffic Law Enforcement; Occupant Protection; Alcohol and Other Drugs
Transportation Research Record 2584

Authors present research on transportation safety issues, from risky teen driving to the mobility behaviors of older adults. Also included are the impacts of red light cameras and the effects of fatigue and alcohol on driving performance.

2016; 112 pp.; TRB affiliates, $53.25; nonaffiliates, $71. Subscriber category: safety and human factors.

Truck and Bus Safety; Roundabouts
Transportation Research Record 2585

Many aspects of roundabouts are examined in this volume, including the benefits of metering systems, an analysis of rear-end collisions, and a study of the rollover propensity of heavy vehicles.

2016; 82 pp.; TRB affiliates, $43.50; nonaffiliates, $58. Subscriber categories: safety and human factors, operations and traffic management, vehicles and equipment.

Pedestrians
Transportation Research Record 2586

Factors influencing the behavior of pedestrians are the focus of this volume, including panic during evacuation, the effects of changes in street layout, countdown pedestrian crossing signals, distractions, shared street space, and surrogate safety measures.

2016; 140 pp.; TRB affiliates, $57; nonaffiliates, $76. Subscriber categories: pedestrians and bicyclists, safety and human factors.

Bicycles and Motorcycles
Transportation Research Record 2587

These 17 papers explore bicycle- and motorcycle-related issues such as child education, bikesharing systems user behavior, nighttime intersection hazards for two-wheelers, and insurance data on motorcycle at-fault crash injuries.

2016; 160 pp.; TRB affiliates, $60.75; nonaffiliates, $81. Subscriber categories: pedestrian and bicyclists, vehicles and equipment, safety and human factors.

Highway Design
Transportation Research Record 2588

This volume addresses such highway design issues as the implementation of cross-slope breaks, horizontal curves, shared space, energy-absorbing concrete barriers, tree planting, and more.

2016; 188 pp.; TRB affiliates, $60.75; nonaffiliates, $81. Subscriber categories: design, highways, operations and traffic management.

Pavement Management 2016, Volumes 1–3
Transportation Research Records 2589–2591

These three volumes explore asphalt and concrete: rutting, fatigue, cracking, structural behavior, the impact of climate, strategies for cost-effective rehabilitation, friction, water evacuation, and more.

2016; Vol. 1: 180 pp.; TRB affiliates, $60.75; nonaffiliates, $81; Vol. 2: 152 pp.; TRB affiliates, $57.75; nonaffiliates, $77; Vol. 3: 76 pp.; TRB affiliates, $57; nonaffiliates, $76. Subscriber categories: Vol. 1: pavements, design and construction, environment; Vols. 2, 3: pavements, design and construction.

The TRR Online website provides electronic access to the full text of more than 15,000 peer-reviewed papers that have been published as part of the Transportation Research Record: Journal of the Transportation Research Board *(TRR) series since 1996. The site includes the latest in search technologies and is updated as new TRR papers become available. To explore TRR Online, visit www.TRB.org/TRROnline.*

Estimating Highway Preconstruction Services Costs, Volume 1: Guidebook; Volume 2: Research Report
NCHRP Report 826

This report presents guidance for state departments of transportation and other agencies to estimate preconstruction services costs for transportation project development. Volume 1 addresses principal sources and components of these costs, estimating methodologies, trends, and advice on agency policies and practices to control program risk; Volume 2 documents the development of an accurate, consistent, and reliable method for cost estimation.

2016; 216 pp.; TRB affiliates, $59.25; nonaffiliates, $79. Subscriber categories: highways, construction, design.

Navigating Multiagency NEPA Processes to Advance Multimodal Transportation Projects
NCHRP Report 827

Analyzed are approaches to satisfy National Environmental Policy Act (NEPA) requirements for multimodal transportation projects, for adoption by DOTs, local partners, and other sponsors. Case studies illustrate successful practices.

2016; 138 pp.; TRB affiliates, $50.25; nonaffiliates, $67. Subscriber categories: highways, public transportation, environment.

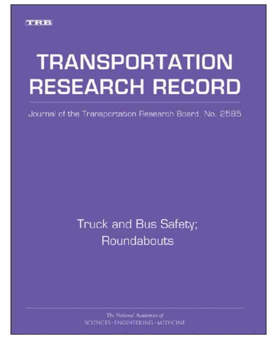
Use of Reclaimed Asphalt Pavement and Recycled Asphalt Shingles in Asphalt Mixtures
NCHRP Synthesis 495

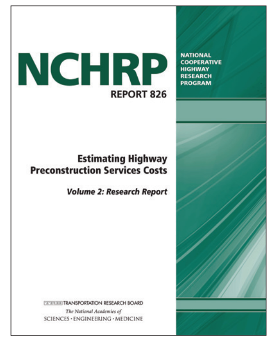
Presented are current practices for the use of reclaimed asphalt pavement and recycled asphalt shingles in the design, production, and construction of asphalt mixtures.

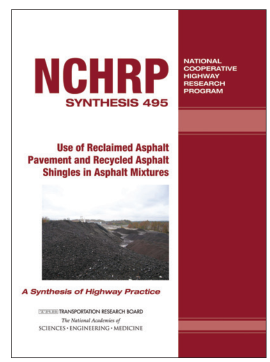
2016; 122 pp.; TRB affiliates, $48; nonaffiliates, $64. Subscriber categories: geotechnology, highways, materials, pavements.

Minimizing Roadway Embankment Damage from Flooding
NCHRP Synthesis 496

This synthesis documents methods to protect roadways and mitigate damage from inundation and







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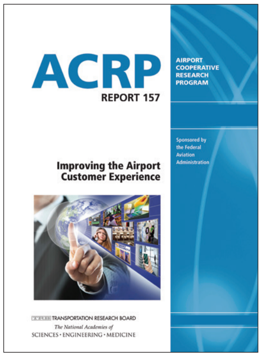

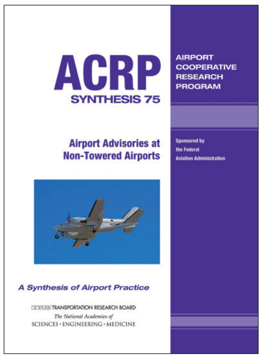

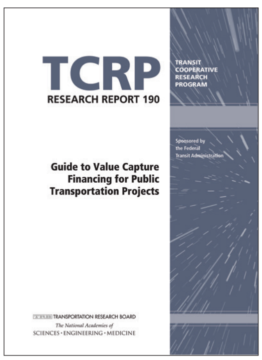

overtopping. Also highlighted are major issues and design components specific to roadway embankment damage from flooding.

2016; 104 pp.; TRB affiliates, $47.75; nonaffiliates, $61. Subscriber categories: highways, geotechnology, hydraulics and hydrology.

Improving the Airport Customer Experience
ACRP Report 157

This report documents notable and emerging practices in airport customer service management and identifies customer improvements for airports to adopt.

2016; 240 pp.; TRB affiliates, $60.75; nonaffiliates, $81. Subscriber categories: aviation, safety and human factors, terminals and facilities.

Deriving Benefits from Alternative Aircraft-Taxi Systems
ACRP Report 158

Explored in this volume are approaches that may reduce fuel use, emissions, and costs for aircraft on the ground. Also presented are the benefits of alternative approaches to taxiing aircraft in movement areas.

2016; 28 pp.; TRB affiliates, $32.25; nonaffiliates, $43. Subscriber categories: aviation, environment.

Pavement Maintenance Guidelines for General Aviation Airport Management
ACRP Report 159

This volume helps general aviation airport managers determine the most cost-efficient, appropriate preventive maintenance solutions to common pavement issues. An interactive airport pavement maintenance recommendation tool and field guide accompany the report.

2016; 235 pp.; TRB affiliates, $63.75; nonaffiliates, $85. Subscriber categories: aviation, pavements.

Airport Advisories at Nontowered Airports
ACRP Synthesis 75

Comprising a telephone interview survey, six case examples, and a literature review, this synthesis documents the ways in which nontowered airports provide advisories to pilots on winds, traffic, and the runways in use.

2016; 58 pp.; TRB affiliates, $38.25; nonaffiliates, $51. Subscriber categories: aviation, security and emergencies.

Helicopter Noise Information for Airports and Communities
ACRP Synthesis 76

This synthesis examines the results of a literature review and a survey of ten airports to summarize the impact of outreach, helicopter noise management programs, technology, and noise abatement procedures.

2016; 135 pp.; TRB affiliates, $50.25; nonaffiliates, $67. Subscriber categories: aviation, environment.

Airport Sustainability Practices
ACRP Synthesis 77

This title compiles information about airport sustainability practices to add to the Sustainable Aviation Guidance Alliance website, which was developed to assist airport operators establish and maintain sustainability programs.

2016; 39 pp.; TRB affiliates, $34.50; nonaffiliates, $46. Subscriber categories: aviation, environment.

Guide to Value Capture Financing for Public Transportation Projects
TCRP Report 190

Presented in this report are the requirements necessary to create value through transportation infrastructure investment and to capture a portion of that value through specific mechanisms.

2016; 106 pp.; TRB affiliates, $50.25; nonaffiliates, $67. Subscriber category: public transportation.

Multiagency Electronic Fare Payment Systems
TCRP Synthesis 125

Explored is current practice in—and the benefits and challenges of—smart cards and other electronic fare payment systems. This volume covers use in multimodal, multiagency environments and uses existing examples to review next-generation approaches.

2017; 121 pp.; TRB affiliates, $50.25; nonaffiliates, $67. Subscriber categories: administration and management, data and information technology, public transportation.

Successful Practices and Training Initiatives to Reduce Accidents and Incidents at Transit Agencies
TCRP Synthesis 126

This report looks at programs that have been effective in reducing accidents at transit agencies: bus operator training, system approaches to address safety hazards, driver incentive programs, technology applications, and infrastructure modifications.

2017; 80 pp.; TRB affiliates, $48; nonaffiliates, $64. Subscriber categories: education and training, passenger transportation, public transportation, safety and human factors.

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TR NEWS

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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, marine, 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, security, logistics, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 words (12 double-spaced, typed pages). Authors also should provide charts or tables and high-quality photographic images with corresponding captions (see Submission Requirements). 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 improve a reader's understanding of 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 photographs 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 appears. 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.

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

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

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◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word, on a CD or as an e-mail attachment.

◆ Submit original artwork if possible. Glossy, high-quality black-and-white photographs, color photographs, and slides are acceptable. Digital continuous-tone images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi. A caption should be supplied for each graphic element.

◆ Use the units of measurement from the research described and provide conversions in parentheses, as appropriate. The International System of Units (SI), the updated version of the metric system, is preferred. In the text, the SI units should be followed, when appropriate, by the U.S. customary equivalent units in parentheses. In figures and tables, the base unit conversions should be provided in a footnote.

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