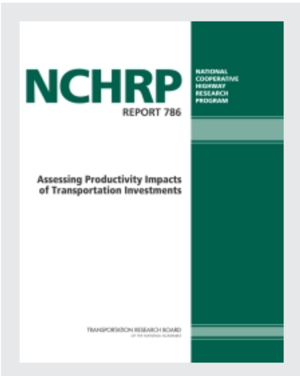


Assessing Productivity Impacts of Transportation Investments

DETAILS

129 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-28425-7 | DOI 10.17226/22294

AUTHORS

Weisbrod, Glen; Stein, Naomi; Williges, Christopher; Mackie, Peter; Laird, James; Johnson, Daniel; Simmonds, David; Ogard, Elizabeth; Gillen, David; and Roger Vickerman

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 786

Assessing Productivity Impacts of Transportation Investments

Glen Weisbrod and Naomi Stein
ECONOMIC DEVELOPMENT RESEARCH GROUP, INC.
Boston, MA

Christopher Williges
SYSTEM METRICS GROUP, INC.
San Francisco, CA

Peter Mackie, James Laird, and Daniel Johnson
INSTITUTE FOR TRANSPORT STUDIES, UNIVERSITY OF LEEDS
Leeds, England

David Simmonds
DAVID SIMMONDS CONSULTANCY, LTD.
Cambridge, England

Elizabeth Ogard
PRIME FOCUS, LLC
DePere, WI

David Gillen
SAUDER SCHOOL OF BUSINESS, UNIVERSITY OF BRITISH COLUMBIA
Vancouver, BC, Canada

Roger Vickerman
UNIVERSITY OF KENT
Canterbury, England

Subscriber Categories
Economics • Freight Transportation • Planning and Forecasting

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2014
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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

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

NCHRP REPORT 786

Project 02-24
ISSN 0077-5614
ISBN 978-0-309-28425-7
Library of Congress Control Number 2014944673

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

The Transportation Research Board of the National Academies, the National Research Council, and the sponsors of the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the report.

Cover photos: FEMA News Photo.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. C. D. Mote, Jr., is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Victor J. Dzau is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. C. D. Mote, Jr., are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR NCHRP REPORT 786

Christopher W. Jenks, *Director, Cooperative Research Programs*
Christopher Hedges, *Manager, National Cooperative Highway Research Program*
Andrew C. Lemer, *Senior Program Officer*
Sheila Moore, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Hilary Freer, *Senior Editor*

NCHRP PROJECT 02-24 PANEL
Field of Administration—Area of Economics

Patrick E. Morin, *Washington State DOT, Olympia, WA* (Chair)
Barry Padilla, *California DOT, Sacramento, CA*
Alexander Heil, *Port Authority of New York and New Jersey, New York, NY*
Joshua L. Rosenbloom, *University of Kansas, Lawrence, KS*
Robert T. Russell, *Guanajuato, Mexico*
Denise D. Whitney Dahlke, *Oregon DOT, Salem, OR*
Rabinder K. Bains, *FHWA Liaison*

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 02-24. Economic Development Research Group, Inc. was the prime contractor for this study, supported by Systems Metrics Group, the University of Leeds, David Simmonds Consultancy, Prime Focus, and additional consultants.

This report is the product of a collaborative effort of researchers including the following:

- Economic Development Research Group, Inc.—Glen Weisbrod (principal investigator) and Naomi Stein, with assistance from staff members: Chandler Duncan, Derek Cutler, and Brian Alstadt, and additional assistance from consultants Daniel Brod, John Stevens, and Michael Brown;
- System Metrics Group, Inc.—Christopher Williges;
- Institute for Transport Studies, University of Leeds (UK)—Peter Mackie, James Laird, and Daniel Johnson;
- David Simmonds Consultancy, Ltd. (UK)—David Simmonds;
- Prime Focus, LLC—Elizabeth Ogard;
- David Gillen (Sauder School of Business, University of British Columbia);
- Roger Vickerman (University of Kent).

The Study team is grateful to the Wasatch Front Regional Council (the Salt Lake City area MPO) and its staff for allowing its travel demand model to be used for this project, and for supporting the project team in this effort. The study team is also grateful to Sharada Vadali of the Texas A&M Transportation Institute for suggestions and insights.

Responsibility for any errors in the content of this report lies entirely with the authors.

FOREWORD

By Andrew C. Lemer
Staff Officer
Transportation Research Board

NCHRP Report 786: Assessing Productivity Impacts of Transportation Investments presents a methodology for analyzing productivity effects of transportation system improvements. The analysis is intended to inform decisionmakers—for example, regional transportation planning agencies, local-government agencies, and elected officials—making choices among alternative investments that may yield a variety of benefits. The methodology involves first screening investments to identify those for which a relatively simplified analysis may be helpful; those requiring more extensive analysis require application of advanced regional economic models. The guidance addresses data needs, availability, and sources to support the analysis; agency staff capabilities; and audiences for information on productivity improvements. This report will be useful to DOT staff and others responsible for project evaluation and presentation of evaluation results to decisionmakers.

State departments of transportation (DOTs) and other agencies generally must consider many more opportunities for improving their transportation systems than they have funding to implement. Agency staff must evaluate the relative merits of investment options to determine which will produce the greatest benefit for taxpayers and citizens—the system's owners. DOTs typically use various methods to make these evaluations in terms of multiple objectives such as enhanced safety, environmental protection, and cost savings. These methods include multi-criteria analysis (MCA) and benefit-cost analysis (BCA). MCA involves rating and scoring proposed investments on a single or multiple scales; multiple scales may include, for example, life-cycle cost, environmental impact, and road-user safety impact. BCA relies on estimation of the economic value of an investment's several costs and benefits accruing over the lifetime of that investment, measured in monetary terms.

Under either approach, travel-time savings are typically a substantial component of benefit attributed to the investment. These savings are enjoyed by the transportation system's users but have only a general relationship with the productivity of the region's specific businesses and labor force. Productivity gains for businesses, in particular, are in principle an important consequence of transportation system improvements but critics argue that current MCA and BCA practices generally neglect the wider economic productivity gains attributable to transportation system improvements.

Fast and reliable delivery of goods and services, for example, can (1) reduce the need for delivery vehicles, warehouse space, and investment in equipment and facilities; and (2) increase the rate at which workers can complete their tasks. Many economic activities simply could not continue without effective transportation facilities. The cumulative effect of multifactor productivity gains can influence the competitiveness of firms in a region and the attractiveness of the region for companies and workers considering relocation from other areas.

The objective of NCHRP Project 02-24, "Economic Productivity and Transportation Investment Priorities," was to develop a methodology and guide for incorporating productivity gains in analysis and prioritization of transportation investments. The intent was that the methodology and guide would encourage DOTs and other agencies to apply consistent analysis methods to produce results that facilitate public decision making about transportation improvement priorities within a state or other large region.

The research was conducted by a team led by Economic Development Research Group, Inc., of Boston, MA. The research team conducted a critical review of literature on the links between transportation system performance and economic productivity, including theoretical research and empirical studies and micro- as well as macro-economic perspectives. A literature review document prepared in the project's first phase supported the team's subsequent work to characterize the influence of transportation system performance on total factor productivity and how the influence of system improvements on productivity may be explicitly assessed. The team considered the factors driving multifactor productivity improvement, the characteristics of regional economies that make them susceptible to influence by transportation improvements, and how increased productivity attributable to transportation system improvements in a region may be projected.

The team then formulated a procedure for analyzing the productivity effects of transportation system improvements. The procedure involves screening investments to identify those for which a relatively simplified analysis may be helpful. Investments requiring more extensive analysis require application of advanced regional economic models. The research team then prepared guidance for incorporating productivity gains into analysis for prioritizing transportation investment projects. The guidance addresses data needs, availability, and sources to support analysis and agency staff capabilities. This final report is meant to be used by DOT staff and others responsible for project evaluation and presentation of evaluation results to decisionmakers.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Assessing Productivity Impacts of Transportation Investments

Overview—This report presents research for assessing the economic productivity impacts of proposed transportation investments and using those results for transportation project evaluation. It is designed for use by state, regional, and local agencies, and can be used to help assess individual project proposals or enhance prioritization processes. Since agencies differ in resources and capabilities, the research presents a framework of calculation steps, provides a choice of methods for carrying them out, and discusses how the results can be incorporated into various project impact analysis methods.

Motivation—Interest in this topic comes from two directions: growing public understanding of the importance of infrastructure to support economic development, and growing recognition among analysts that wider economic benefits are not being fully captured in current evaluation methods. Productivity impacts are an integral aspect of both economic competitiveness and wider economic benefits.

Importance—This research has several uses. First, it provides a foundation for transportation agency staff and executives, as well as elected officials, to understand the distinction between standard traveler benefits, wider transportation metrics, and economic impacts.

Second, it identifies the performance impact metrics that are already commonly collected by transportation agencies and shows how they relate to business productivity. It also identifies what is missing in current transportation performance measurement—reliability, accessibility, and intermodal connectivity measures—and explains why adding them can matter for assessing the benefits and impacts of transportation projects. For transportation agency staff and decisionmakers, it lays out a case for why it is worthwhile to take additional time and effort to gather that information.

Third, it presents a straightforward set of steps that rely on spreadsheet calculations to assess the productivity impact of projects, and then use those impact results for benefit-cost analysis, economic impact analysis, or multi-criteria scoring of proposed projects.

Core Elements—The research has the following six steps:

1. Screening to assess whether productivity impact analysis is appropriate for a project;
2. Identification of types of transportation impact factors that need to be analyzed and analysis tools available for measuring them;
3. Calculation of direct effects on travel-related business costs, based on standard transportation data;
4. Calculation of wider transportation impacts, in terms of travel time variability, market access, and intermodal connectivity measures;
5. Calculation of productivity impact elements, in terms of transportation-related cost savings, agglomeration impacts, and supply chain technology impacts; and

6. Calculation of overall productivity effects and use of results in evaluation processes including multi-criteria analysis, benefit-cost analysis, and economic impact analysis.

Supporting Materials—Accompanying the report, there are descriptions of available spreadsheet tools that can be used to carry out the calculations. Three detailed case studies show how the analysis steps can be carried out to calculate productivity-related impact metrics. Three appendices discuss issues concerning measurement and bias correction.

Glossary

Agglomeration Economies = Business productivity benefits gained from the ability of firms to tap a larger labor market, customer market, or supplier market, or increase interaction with other firms—all enabled by transportation network improvements. The benefits may be associated with "enhanced matching" or "economies of scale" (due to broader market access), "knowledge spillovers" (due to interaction among firms and workers in clusters), or "technology adoption" (due to integration of supply chain functions).

BCA = Benefit-Cost Analysis

Benefit-Cost Analysis (term used in North America) = Process for analyzing the efficiency of investment by expressing benefits and costs in money terms, calculating the net present value of those benefit and cost streams, and comparing them. Outside of North America, this is more commonly referred to as "cost-benefit analysis."

Buffer Time = Amount of time that must be added to average travel times to ensure an on-time arrival (most commonly defined by businesses as the schedule padding necessary to achieve 95 percent on-time performance)

Capital Productivity = Ratio of total business output (value added) per dollar of capital (money) investment in equipment and materials

CBA = Cost-Benefit Analysis

CGE = Computable General Equilibrium

Computable General Equilibrium Model = Type of macroeconomic impact model that employs market-clearing equilibrium concepts to simulate impacts of a policy on supply, demand, prices, and flows of labor, capital, delivered goods, and services

Consumer Surplus = Measure of the social benefit to consumers because the going price is lower than the consumer's willingness to pay for a product or service. This is considered a social benefit and is not counted in the analysis of productivity gains.

Cost-Benefit Analysis (term used outside of North America) = Benefit-Cost Analysis

DOT = Department of Transportation (government agency)

Economic Impact Analysis = Process for analyzing the effects of a project (or policy) on the growth of jobs, income, investment, or value added in a given area

Economies of Scale = Advantages of reduced unit cost that occur when a business increases the scale of its operation and can spread fixed costs over more units of output

EIA = Economic Impact Analysis

Factor Productivity = Ratio of total business output (value added) relative to a unit of a given factor of production

GDP = Gross Domestic Product

Generalized Cost = Term used in travel demand modeling to reflect the "impedance" or overall cost of travel between zones. Most often a composite measure of both the value of travel time and level of vehicle operating cost involved in movement between zones; in some cases, it can include other factors such as comfort.

Gross Domestic Product (GDP) = Amount of business value that is generated in a given nation, state, or region; this is almost the same as Gross Value Added but it adds further adjustments for taxes paid (+) and subsidies received (−) by business units

Gross Regional Product (GRP) = Value for a state or region within a nation

Gross Value Added = Value Added = Value of goods and services produced minus the cost of "intermediate consumption" (i.e., non-labor inputs)

GRP = Gross Regional Product

GVA = Gross Value Added

Incident = Traffic collision or breakdown that leads to time delays

Imperfect Competition = Term referring to how the real world differs from classical economic theory due to limited sellers, limited buyers, or differentiated qualities in workers and products. It can cause prices to exceed marginal costs, and "agglomeration economies" associated with better matching of worker skills to business needs

Induced Demand = Additional travel (either in the form of more trips or trips to more distant destinations) caused by completion of a new transportation project, which would otherwise not have occurred

Intermodal Connectivity = Increase in access to destinations enabled by use of an air, marine, or intermodal rail terminal transfers

Labor Productivity = Ratio of total business output (value added) per worker

Localization Economies = Business productivity benefits gained from the ability of firms to interact with other similar or complementary firms nearby (a form of agglomeration benefit)

Logistics Cost = Costs for freight handling, including costs of loading dock handling, inventory warehousing, and product delivery

MAP-21 = "Moving Ahead for Progress in the 21st Century Act," U.S. Public Law P.L. 112–141, enacted in 2012 to provide federal transportation funding and regulation

MCA (MCDA) = Multi-Criteria Analysis, also referred to as Multi-Criteria Decision Analysis

MPO = Metropolitan Planning Organization

Multi-Criteria Analysis = Process for rating projects in terms of a series of criteria, each of which has a preset weight that is applied to calculate a composite score

Multi-factor Productivity = Measure of total factor productivity used in the United States

Output = Value of business production. For productivity analysis, it is measured as net Value Added (for other analyses, it may be measured as gross business revenue).

Partial Productivity = Measure of productivity that applies for specific parts of the business operation of a designated type of business activity

Passenger Travel Time = Aggregate measure of total passenger travel time on a public transportation mode, calculated as the average number of passenger trips occurring in a given period (day, month, or year) times the average travel time per passenger-trip

Productivity = Ratio that reflects the level of output generated from a given amount of input. It is a measure of business efficiency.

Productivity Elements = Term used in this report to denote four elements of value added: direct cost savings, value of enhanced reliability, value of enhanced market access, and value of connectivity to intermodal ports and terminals

PTT = Passenger Travel Time

Standard Deviation of Travel Time = Range of travel time variation that accounts for roughly 68 percent of all cases

Standard Traveler Benefit = Term used in this report to denote the traditional valuation of user benefits in terms of the value of travel time, vehicle operating cost, and safety benefits. This is similar to the concept of "standard transport economic efficiency (TEE)" that is referenced in the UK's Transport Appraisal Guidance.

STB = Standard Traveler Benefit

TAZ = Traffic Analysis Zone, used in transportation planning models

Total Factor Productivity = Ratio with total business output (value added) divided by the total cost of all labor, capital, and service inputs required to produce it

Traveler Benefit = Benefit to travelers, including driver, passenger, and vehicle time; cost and safety benefits

Travel Time Index = Ratio of average travel time under congested conditions, divided by average travel time under free-flow conditions

TIGER (Transportation Investment Generating Economic Recovery) = Discretionary grant program of the U.S. Department of Transportation

TTI = Travel Time Index

Urbanization Economies = Business productivity benefits gained from the ability of firms to gain access to a larger labor or supplier market in adjacent or surrounding areas (a form of agglomeration benefit)

User Benefit = Measure of the benefits to users of a facility or system, often equated with traveler benefits, though it also includes benefits for freight shippers who are seen as additional users of the transportation system

Value Added = Measure of business output (revenue from product sales) minus the cost of nonlabor inputs used to produce that product

V/C = Ratio of volume to capacity

Vehicle-Hours of Travel = Aggregate measure of total vehicular travel time on roads, calculated as the average number of vehicles traveling in a given period (day, month, or year) times the average travel time per vehicle-trip

Vehicle-Miles of Travel = Aggregate measure of total vehicular use of roads, calculated as the average number of vehicles traveling in a given period (day, month, or year) times the average trip length (miles per trip)

VHT = Vehicle-Hours of Travel

VMT = Vehicle-Miles of Travel

Wider Economic Benefits = Class of economic benefits that go beyond the Standard Traveler Benefits included in Benefit-Cost Analysis; they include both agglomeration benefits and business reorganization or technology adoption benefits that are enabled by wider transportation impacts

Wider Transportation Impact = Label used in this report to denote transportation impacts that are beyond travel time, vehicle operating cost, and safety impacts (includes reliability, accessibility, and intermodal connectivity impacts)

CHAPTER 1

Introduction: Understanding Productivity

This chapter explains the research project goals and topics, defines productivity, explains how transportation projects can affect productivity, and summarizes the state of analysis methods for measuring productivity impacts of transportation investments.

1.1 Motivation and Overview

Report Objective

The objective of NCHRP Project 02-24 is "to develop a methodology and guide for assessing economic productivity gains and analysis for prioritization of transportation investments. The goal of this project is to bring the consideration of economic productivity into the mainstream by developing methods that are both consistent and practical, and usable in transportation investment decision making for a state or region."

This report is designed for use by state departments of transportation (DOTs) and metropolitan planning organizations (MPOs), to aid in project prioritization and decision making. However, it can have much wider uses for other types of organizations and other types of decision making. Since agencies differ in their resources and capabilities, the report presents a general framework, explains how it can be followed with methods ranging from simple to sophisticated, and discusses implications of those choices. It builds upon a review of existing research and practice regarding the estimation and use of productivity impact metrics, which is covered in a separate, companion document (Economic Development Research Group, et al., 2012).

Background Motivation

Over the last decade, there has been growing interest among U.S. transportation agencies in improving methods and systems for evaluating the economic impacts of transportation projects. Part of this interest can be attributed to the federal MAP-21 funding authorization that calls for greater attention to showing the long-term benefits of proposed projects from a national, as well as local, perspective. Public financing constraints also have led public leaders and agency decision-makers to demand more information about proposed public expenditures for transportation projects in terms of the return on investment, business case, or expected job and income benefits from funding proposed projects. In a limited capital environment, the private sector also is demanding greater return on their investment as competition increases for capital investment funds.

The specific interest in productivity comes from a growing body of research demonstrating that there are wider economic benefits associated with reliability, accessibility, and connectivity enhancement that are not being fully captured by the benefit-cost, economic impact, and multi-criteria rating systems commonly in use for transportation investment assessment. Those are key factors that can lead to enhanced productivity and economic growth. The interest in productivity impacts in the United States also has been reinforced in recent years by the language of both federal legislation such as MAP-21, which calls for funding projects that "increase productivity, particularly for domestic industries and businesses that create high-value jobs" (U.S. Congress, 2012) and U.S.DOT grant program rules like TIGER criteria that give priority to transportation improvements that "increase the economic productivity of land, capital, or labor at specific locations" (U.S.DOT, 2011).

Prior Work: Review of Research and Practice

To further examine these trends, the research team for this project conducted a broad literature review of research and practice regarding the evaluation of transportation investment impacts on productivity. This included the following:

- Review of academic research regarding the definition and measurement of productivity, and the effects of transportation system changes on both the elements of productivity and factors that drive productivity change;
- Interviews with representatives of U.S. state dots and MPOs, and selected industry and port authority representatives, regarding how their agencies assess the economic impacts of proposed projects and incorporate information on productivity into their investment decision-making processes; and
- Overview of the state of practice in assessing productivity and wider economic benefits to support transportation investment decision-making in England, Scotland, the Netherlands, France, and Germany.

The review of research and practice is reported in a separate document, *NCHRP Project 02-24: Literature Review and Stakeholder Perspectives* (Economic Development Research Group, et al., 2012). *NCHRP Report 786* is a companion document that builds on this earlier research to provide guidance on how transportation agencies can incorporate productivity impacts into transportation investment decision making.

Audiences and Uses

This report has several uses. First, it provides a foundation for transportation agency staff and executives, as well as elected officials, to understand the distinction between standard traveler benefits, wider transportation metrics, and economic impacts.

Second, it identifies the transportation performance impact metrics that are already commonly collected by transportation agencies and shows how they relate to business productivity. It also identifies what is missing in current transportation performance measurement—reliability, accessibility, and intermodal connectivity measures—and explains why adding them can matter for assessing the benefits and impacts of transportation projects. For transportation agency staff and decisionmakers, it lays out a case for why it is worthwhile to take additional time and effort to gather that information.

Third, it presents a straightforward and practical set of steps that staff of any transportation planning agency can apply to assess the productivity impact of projects, and then use those impact results for benefit-cost analysis, economic impact analysis, or multi-criteria scoring of proposed projects.

Overall, *NCHRP Report 786* makes it clear that (1) there are wider transportation benefits that can be measured, (2) this information can be used to improve project evaluation and prioritization processes, and (3) the process of carrying this out can be done by any agency if it has the available staff resources (or budget to hire others) to carry out the process. Of course, this last part is the catch, for many state DOTs and MPOs are constrained in terms of staff resources and budgets. Yet, even in those cases, it can be useful for agencies to acknowledge the existence of broader economic impacts in their project evaluation processes, and to draw on the screening criteria presented in this report to identify where those broader impacts are most likely to be important.

Overview of this Report

The remainder of Chapter 1 defines productivity, the relationship between transportation system changes and resulting economic productivity change, and methods for measuring productivity.

Chapter 2 discusses the use of productivity measurement in transportation investment decision making—when it is appropriate and how it can be used through methods such as multi-criteria analysis, benefit-cost analysis, and economic impact analysis.

Chapter 3 explains the overall framework and detailed sequence of steps for calculating productivity impacts of proposed transportation investment projects. It includes a discussion of data requirements, sources of information, calculation worksheets, and available models and tools that can be used to complete the calculations.

Chapter 4 provides three detailed case studies, illustrating how the Chapter 3 steps can actually be carried out to calculate productivity-related impact metrics. The case studies involve hypothetical road and rail system improvements intended to enhance reliability, access, and intermodal connectivity for affected areas.

Chapter 5 describes and critically reviews the features of available models and tools that can be used to carry out the steps in Chapter 3. These include tools for the assessment of reliability, access, connectivity, supply chain change, and regional economic impacts.

There are three appendices. Appendix A discusses options for correcting overlap and estimation bias; Appendix B provides more detailed technical discussion of issues regarding the calculation of agglomeration benefits; and Appendix C discusses needs for further research.

1.2 Defining Productivity and Transportation Effects

Formal Definition of Productivity

Productivity = {output produced}/{inputs required}

Productivity is a ratio that reflects the level of output generated from a given amount of input. It is a measure of business efficiency. The concept of productivity is always defined in terms of a specific area and can be developed for any unit of economic activity—including an individual firm, a specific industry or the entire economy—within a specified region, state, or nation. There are many facets of productivity; they are discussed in Section 1.4.

How Transportation Directly Leads to Economic Productivity Impacts

Transportation improvements serve to change characteristics and pattern of travel and access between places—at a local, regional, or national level. They lead to impacts on productivity by affecting flows between elements of the economy. Figure 1-1 illustrates the ways in

This is a high-level summary of the transportation–productivity relationship. For further details, see the NCHRP Project 02-24 Literature Review (Economic Development Research Group et al., 2013).

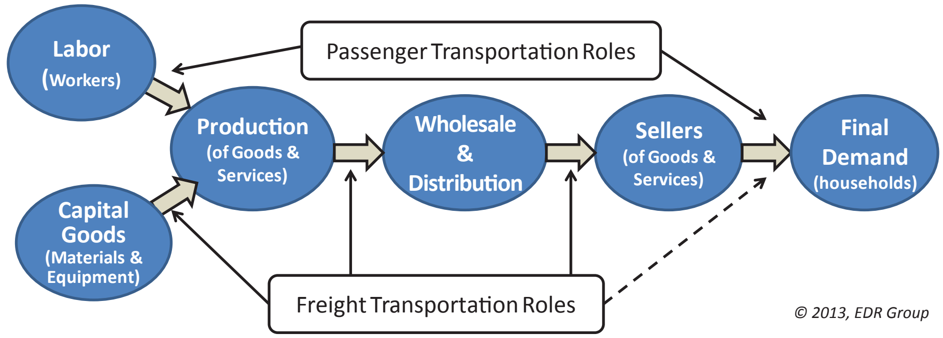


Figure 1-1. Transportation roles in the economy.

which passenger and freight flows from the "factors of production" (labor and capital) to produce goods and services, and then through the supply chain (from production to distribution to retail sales to households).

In Figure 1-1, each of the stages—from production to retail sales—has two key characteristics: (1) it brings some value added to products that are sold; and (2) it depends on transportation for incoming freight and outgoing deliveries as well as worker commuting and customer access.

Figure 1-1 is a stylized and simplified diagram, because both labor and capital are inputs not only to production, but also to each of the subsequent stages. In addition, retail products are sold not just to households (final demand), but also to businesses that serve earlier production and distribution steps. However, the key point is that any specific form of transportation project improvement may affect a unique combination of elements of the economy. And any effects of the transportation project on costs and quantities produced or required for any of these elements may also lead to a change in economic productivity.

The dominant categories of economic productivity impact are summarized below.

- **Efficiency (Cost Reduction) Effects**—The most straightforward effect of transportation infrastructure improvement is on the cost of transportation-related operations. Shorter distances, faster speeds, and reduced incident delays can directly reduce labor, equipment, and operating costs for worker travel and freight shipments. These effects are typically captured by standard travel benefit evaluation methods. However, they also can lead to broader effects on businesses and the entire economy, because transportation cost savings can lower the price of inputs to production and lower the cost of distributing products (or services) to markets.
- **Technology Adoption Effects**—Another form of transportation impact is on enabling the adoption of new business operating processes and technologies. Reductions in traffic congestion, bottlenecks, and collision rates can improve reliability—which is seldom reflected in current transportation project evaluations. Enhancement in service scheduling, freight handling, and coordination of transfer processes at air/sea ports, national borders, and intermodal transfer terminals also can improve supply chain "fluidity" by affecting both the reliability and speed of supply chain movements.

  These improvements can enable broader adoption of technologies (such as just-in-time manufacturing and lean supply chain processing) with more centralized manufacturing and distribution locations, reduced inventory levels and reduced need for safety stocks, backup delivery vehicles, and extra loading dock workers. Those technology and associated operational changes also can enable longer distance supply chains and broader customer delivery areas, leading to a reorganization of economic activity in terms of the centralized location and consolidation of facilities. All of these effects can ultimately affect labor and capital requirements for manufacturers as well as their material suppliers, service vendors, and product buyers.

- **Agglomeration/Access Benefits—**Yet another form of transportation impact is on enhancing access and connectivity between firms and their workers, suppliers, and customers. *Agglomeration economies* are business benefits associated with the centralization of activity, meaning that firms in some sectors of the economy gain productivity from the ability to share a larger pool of labor, a broader set of suppliers, or by increased interaction with other firms in ways that improve the match between needs and availability (e.g., specialized products shipped from suppliers to final producers, or in the skills of worker and skills needed by firms). Agglomeration economies also result from improved learning and dissemination of skills and ideas enabled by the presence of firms that can cluster to take advantage of those broader advantages. The result can be an increase in labor productivity.

  Market access benefits are a form of agglomeration economies, and that relationship can play out in several ways: (1) by expanding the customer delivery market that can be effectively served in a day from a given business location, (2) by expanding the effective breadth of same-day parts or materials suppliers that can deliver to that location, and (3) by expanding the effective size or effective density of the available labor market, potentially increasing the availability of workers with required specialized worker skills needed by some firms. Any of these effects can bring reorganization of business activities as they enable shifts to larger, more centralized facilities. That can bring *economies of scale*—a reduction in the unit cost of production and delivery as the fixed costs of operating larger facilities (and fleets) are spread over more units.

  A similar effect can occur for clusters of technology-based industries with specialized skill requirements, particularly when transportation conditions effectively limit the scale of qualified labor that firms can assemble in one place. In such cases, transportation system improvement may lower commuting costs and enable centralization of office functions in a business cluster, thus further exploiting economies of scale.

Figure 1-2 repeats the prior figure, but adds call-out boxes to illustrate how the various elements of cost efficiency, technology adoption, and agglomeration/access lead to changes in productivity for various elements of the economy.

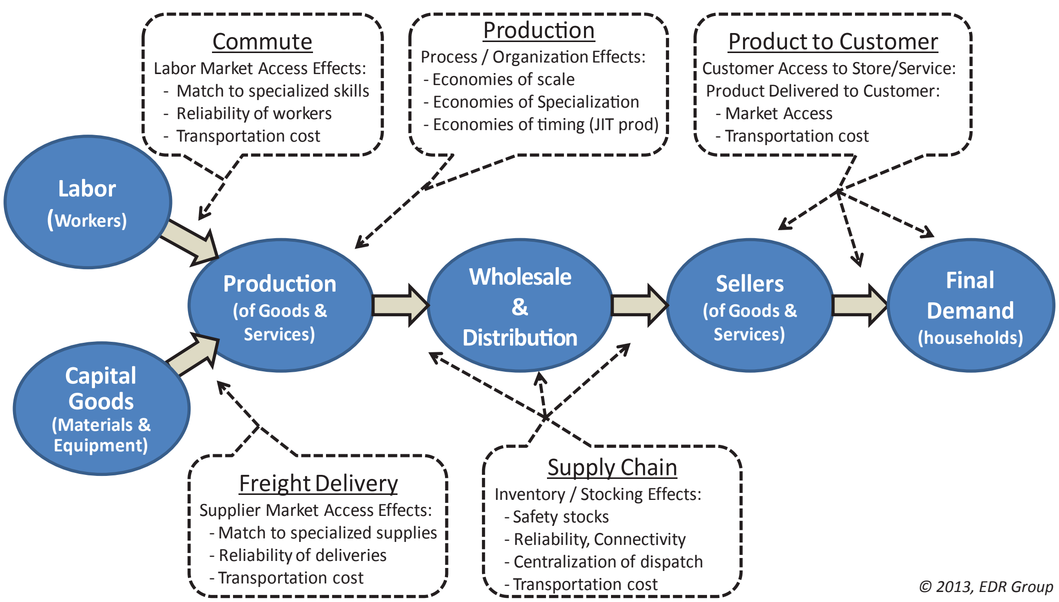


Figure 1-2. Transportation effects on productivity.

Additional Facets of Agglomeration Impact

From the viewpoint of transportation and land-use planning, it also is useful to recognize two types of agglomeration effect that are affected by transportation conditions in different ways, apply to different industry sectors, and lead to different forms of spatial clustering and productivity growth.

- Urbanization economies are associated with the economic mass or density of a specified urban area and hence its market access. For instance, office-based service industries with requirements for specialized technology skills tend to cluster in regions of large metropolitan areas where they can access a sufficiently large base of workers with the required skills. Transportation system improvements can enhance these urbanization economies by enlarging the effective density or size of its surrounding labor market—which can be measured with available analysis tools.
- Localization economies are associated with the connectivity or density of specific types of economic activity. For instance, auto assembly and parts plants are concentrated along three interstate highways in the southeastern United States because those highways enable just-in-time production via supply chains that link parts suppliers with assembly plants for same-day deliveries. At a very different scale, the concentration of financial service firms in the downtown areas of large cities represents a combination of urbanization economies (access to a large market) and localization economies (enabling worker and firm interaction in a cluster). More work is needed to develop analysis tools for the measurement of localization effects.

Distinguishing Intermodal Connectivity from Other Access Impacts

Access measures could, in theory, be defined in a way to encompass travel by all modes. In practice, this does not occur. For example, current modeling practice almost never integrates road network time, cost, and access measures with corresponding intercity rail, marine, and air system network measures. As a result, changes in intermodal connectivity enabled by transportation infrastructure improvements are typically measured separately from agglomeration and market access impacts.

There are sound reasons for this approach. First, air, marine, and intercity rail transportation often involves private operators who release limited information about their service performance. Second, intermodal services provide links to markets that are typically outside of what would otherwise be the area modeled by an individual MPO or state DOT. For those reasons, this report treats intermodal connectivity as a separate element of transportation impact measurement, apart from reliability and market access measurement.

The fundamental benefit of an intermodal terminal is that it provides a gateway to access long-distance destinations or outlying market areas via a transfer of modes. For example, Figure 1-3 illustrates how air shuttle services increase the destinations accessible within 2 hours of travel time from Boston Logan Airport, beyond what would otherwise be accessible via ground transportation. In this case, the breadth of markets accessible within a given timeframe is determined by a combination of both the frequency of service and travel times by ground and air modes.

In general, intermodal connectivity can be improved by enhanced road access *to* air, sea, or rail terminals, enhanced air, sea, or rail services to other destinations *from* those terminals, and enhanced opportunities for transfers, or reliability or speed of transfers, *at* those terminals. The first two are access-related effects; the third is an efficiency-related effect.

Broader Effects on Productivity and the Economy

The previously cited efficiency, technology, access, and intermodal connectivity effects lead directly to productivity benefits for firms that rely on the transportation system. Those direct

(cities within 2 hours total travel time from downtown Boston, based on driving a car or flying to destinations that have hourly or more frequent air service during business hours)

Source: EDR Group, et al., 2012

Figure 1-3. Illustration of how intermodal connectivity expands market access.

effects can be measured and considered in the evaluation of transportation projects, plans, and policies. However, they also can lead to even broader changes in the economy of an area, which can affect both economic growth and multi-factor productivity.

The broader changes in the economy occur through both supply side and demand side effects of productivity increases. For instance, business may expand production to meet greater demand for their products, if demand is elastic (i.e., sensitive to price changes). Alternatively, businesses may produce the same output more cost-effectively if demand is inelastic (insensitive to price changes). In many industries, the supply-demand situation is in between those two extremes and a combination of both effects occurs.

Efficiency effects can lead to further, multi-faceted changes in the economy. For instance, reduced commuting costs to an area can make working there more attractive. In the long run, workers in affected areas may not require the same level of compensation (through wages) and people on the margin of working/not working may be tempted into the labor market.

In theory, increased productivity in the transportation services sector can lead to a reduction in transportation sector jobs if the level of business output is not expanded. However, it is more likely that as transportation costs fall and cost competitiveness increases, there will be increased production and shipping of products for at least some industries and regions.

Technology adoption and agglomeration benefits can further lead to the reorganization of firms, as reliability constraints and spatial barriers are reduced. As firms in a region can access a broader customer base in a cost-competitive manner, their output may grow further. Increased global competitiveness can lead to expansion of the national economy; increased domestic access can also lead to the expansion of some regional economies.

Both effects can lead to distributional changes among sectors and locations of economic activity. They can facilitate an expansion in the scale of operations for some firms, while allowing fewer firms to ultimately survive in the marketplace. The end result can be job losses for some business types and locations. However, that outcome can be more than offset by increased domestic and global competitiveness—growing income and demand for products and, ultimately, overall gain for both residents and businesses.

All of these changes in supply and demand for products may lead to changes in their prices over time. Depending on price changes, the relative value of output produced and cost of inputs required to produce them may change. The result is that the productivity ratio can ultimately become larger or smaller than the initially measured impact on users and beneficiaries of the transportation system.

To assess these broader economic impacts, some form of economic modeling is required—most often in the form of regional economic simulation models and sometimes global trade competitiveness models. Such models can provide useful insights, and their use is discussed later in Section 2.2.4. However, neither type of model is needed if the consideration of productivity is focused on the direct productivity effects of projects on firms that rely on the transportation system. That more straightforward type of analysis is the primary focus of this report.

1.3 Relationship to Benefit and Impact Metrics

Alternative Perspectives for Assessing Transportation Project Impacts

The effect of transportation projects on the productivity of firms can be viewed in terms of four measurement perspectives, each of which reflects a different stage in the impact analysis process. The relationships are illustrated in Figure 1-4 and described below.

- **Standard Traveler Benefits**—The most immediate effect of transportation infrastructure capacity improvements is on the observed volume, and speed and safety characteristics of affected passenger and vehicle flows. These are traveler benefit categories that are traditionally measured by transportation planners through the use of either travel demand models or engineering estimates. Changes in routes and their traffic volume are reflected in total VMT (vehicle-miles of travel), while changes in speeds are reflected by total VHT (vehicle-hours of travel).
- **Wider Transportation System Benefits**—Transportation infrastructure improvements can affect other aspects of transportation systems beyond the traditionally observed volume, speed, and safety characteristics. Additional (wider) transportation impacts include changes in an area's reliability of movements, accessibility to markets, and connectivity to, or at, intermodal terminals.

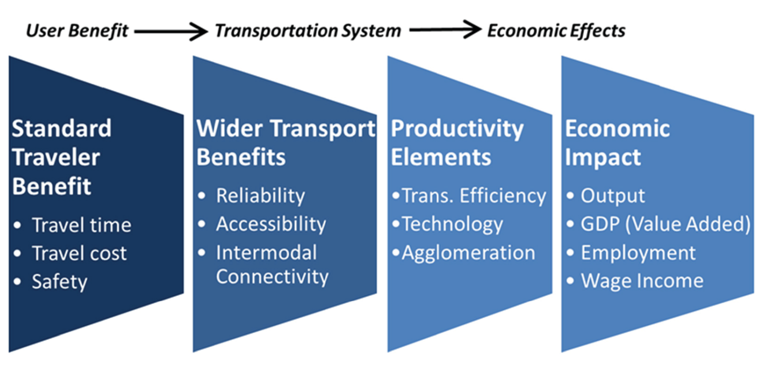


Figure 1-4. Relationship of transportation system, productivity, and economic impact.

- **Productivity Elements—**The transportation impacts (preceding two bullets) can lead to economic changes by reducing business operating costs (enhancing efficiency), increasing technology adoption, and increasing agglomeration benefits in the economy—all elements of productivity.
- **Economic Impact—**Ultimately, shifts in the characteristics of productivity elements (the preceding bullet) lead to impacts on an area's economic growth, as measured in terms of business output, GDP, employment, and income.

Referring to Figure 1-4, transportation system impacts are represented by the left two boxes. They can be viewed as intermediate factors that lead to broader changes in business productivity and ultimately further changes in the economy, which are represented by the right two boxes.

GDP = Gross domestic product
GRP = Gross regional product
GVA = Gross value added, which reflects gross business output (revenue from product sales) minus the cost of non-labor inputs used to produce that product.

In the context of this study, GDP and GRP impacts are essentially the same as GVA impacts. See the Glossary for an explanation of their actual differences.

Measures of Economic Impact and Their Applications

To understand the role of productivity in transportation decision-making, it is useful to distinguish three interrelated terms that are commonly confused: *economic impact, economic benefit*, and *productivity*.

- **The economic impact of a transportation investment** is commonly defined as the effect on growth of total economic activity occurring in an area (which may be a region, state, or nation). It reflects effects of local productivity gain, plus effects of spatial shifts in business investment and business activity patterns among regions (that are driven by differentials in productivity or other cost or revenue factors). In addition, multiplier effects associated with patterns of supplier purchases and consumer spending also can be included. Economic impact models forecast these outcomes, which are commonly measured in terms of change in gross business output, net value added (or GDP), worker income, and/or jobs.
- **The economic value of benefits from a transportation investment** represents societal benefit (i.e., the social welfare gain) and is the numerator in benefit/cost ratios. It reflects local productivity gain in the economy, plus societal benefits that do not directly affect the flow of money in the economy—such as the value of time savings for personal travel, consumer surplus, and the value of reduced unemployment, as well environmental and quality-of-life impacts.
- **The productivity impact of a transportation investment** reflects efficiency gains for business-related travel that are enabled by travel time and travel cost savings, plus wider economic benefits associated with agglomeration and logistics technology efficiencies that are enabled by access, connectivity, and reliability effects on non-travelers as well as travelers. These wider benefits are further defined and explained later in this section.

The key point, which is illustrated in Figure 1-5, is that productivity can be viewed as both a driver of economic growth and an indicator encompassing wider benefits that should be (but in the past have seldom been) included in benefit-cost analysis. This makes productivity impacts of interest and relevance for the following three different uses:

- As part of benefit-cost analysis (BCA)—to support funding and implementation decisions,
- As part of economic impact analysis (EIA)—to support the evaluation of proposed projects and their planning implications, and
- As a stand-alone measure—to inform public policy debate and represent a factor in multi-criteria analysis (MCA) systems that prioritize projects.

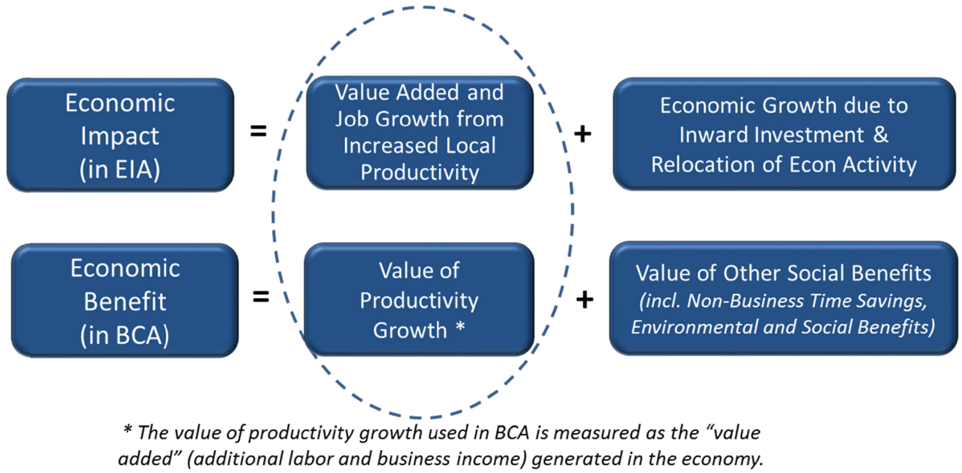


Figure 1-5. Relationship of economic impact, benefit-cost, and productivity metrics.

These three forms of analysis—BCA, EIA, and MCA—are further discussed in Section 2.3.1.

This report is designed to accommodate all three analysis perspectives, making it applicable to a wide range of transportation planning agencies, including state DOTs and MPOs. The guidance in Chapter 3 is intended to enable these agencies to incorporate economic productivity considerations into their existing decision-support analysis methods.

1.4 Alternative Measures of Productivity

Defining Metrics

There is a reason why the productivity effects of transportation investments have seldom been estimated in past studies of project impacts—productivity is multi-faceted and not a simple concept to measure, particularly in the context of evaluating project proposals. In fact, productivity can be measured at three different levels: as partial productivity, factor productivity, and total or multi-factor productivity.

Partial productivity commonly refers to measures of productivity that apply for specific parts of a business operation. These measures are commonly tracked by individual firms and published for specific industries. They do not need to be expressed in money terms. For instance, commonly published measures of partial productivity for transportation industries include the following:

- For railroads: train productivity (gross ton-miles per train), yard productivity (railcars per yard-switch mile), locomotive utilization (trailing gross ton-miles per total horsepower), rail car movement (car-miles per day), and revenue per train mile.
- For trucking companies: miles per driver per day, $ revenue per truck per day, empty/full miles per load, loaded or billed ratio per truck mile, dwell time per customer pickup/drop-off, and total revenue per truck mile.
- For barge companies: loaded ton-miles per barge-day, barge miles per barge-day, and revenue per barge-day.

Factor productivity is a form of partial productivity. It refers to the ratio of business output (value added) occurring in a period of time, per individual factor of production. The latter may be workers or work hours (which leads to a measure of labor productivity), or investment in materials, equipment, and facilities (which leads to a measure of capital productivity). Since all business products and services require some combination of both labor and capital, it is not possible to separate the value of output produced by workers from the value of output produced by capital investment. As a result, the numerator of the labor productivity metric and the numerator of the capital productivity metric are the same number—total business output. The two factor productivity ratios thus differ only in terms of the denominator used to calculate them.

Multi-factor productivity, also known as total factor productivity, portrays the ratio with total business output (or value added) divided by the total cost of all labor, capital, and service inputs required to produce that output. All three measures—labor, capital, and multi-factor productivity—have been calculated for each major industry at a national level by the U.S. Bureau of Economic Analysis. However, only labor productivity can be calculated easily for individual industries at a local and state level. The reason is that the calculation of both capital productivity and multi-factor productivity requires significant information and modeling analysis regarding the mix of capital investment and applicable prices for input goods and services—information that local and state agencies seldom have.

The different options and elements of productivity measurement are described in the OECD Guide (Organisation for Economic Cooperation and Development, 2001) and further discussed in *NCHRP Project 02-24: Literature Review* (EDRG, et al., 2012). These multi-faceted aspects are shown in Figure 1-6. The graphic shows that the numerator of the productivity ratio—business output value—can be measured by several metrics, expressed in terms of either gross output (total product value) or net value added (often represented as gross domestic product). Value added (or GDP) is preferred as the more accurate measure of business activity occurring in an area; it is defined as the value of a product minus the cost of parts, materials, transportation, energy, and utilities. (See Glossary.) This numerator may be measured at a firm-level, industry-wide level, or area-wide level of aggregation.

The denominator of the productivity ratio—business input cost—can be measured relative to labor levels, capital investment, or total cost of all input elements. The factors enabling productivity change resulting from transportation projects—efficiency, technology, and agglomeration factors—may either add to output (the numerator) or reduce the cost of inputs (the denominator) in the productivity ratio.

In other words, the three fundamental measures of overall productivity—labor productivity, capital productivity, and multi-factor productivity—are all ways of expressing the value of

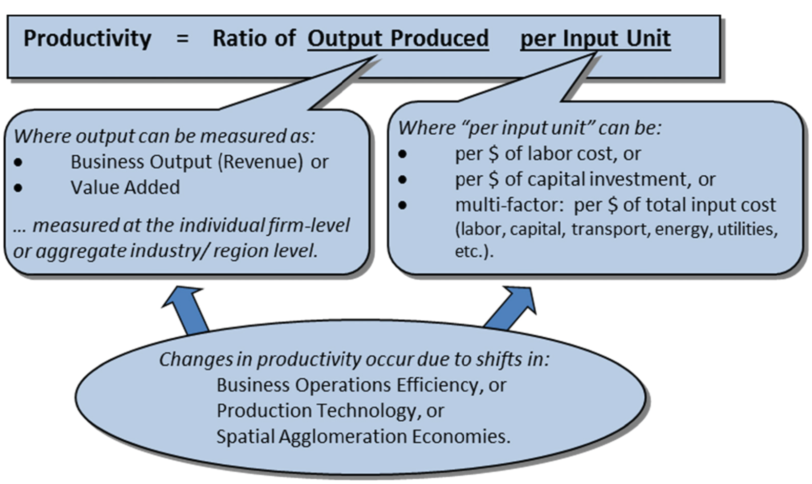


Figure 1-6. Drivers and facets of productivity impact.

generated business output as a ratio to the value of various inputs. They differ in terms of the denominator selected to be the point of reference.

Multi-factor productivity is the most relevant measure for comparing the economic productivity of states or regions. The reason is that areas differ dramatically in their mix of industries, and industries differ dramatically in their relative levels of labor and capital intensity. Labor productivity is far higher in capital-intensive (high automated) manufacturing industries than in labor-intensive personal service industries. However, this does not mean that we must use multi-factor productivity metrics when assessing the incremental benefit of individual transportation projects in specific areas where the mix of industries is set. In fact, that is not practical, for reasons to be explained next.

Practical Considerations in Application for Transportation Decision Making

Consider the requirements for measuring the impacts of a transportation project on labor, capital, and multi-factor productivity. Among these three measures, labor productivity is the most straightforward and easy-to-measure concept. It is most commonly shown as the ratio of output or value added per worker in a given area. In general, information on the number of workers in particular regions and industries, as well as information on associated worker income and value added (or GDP or GRP) is available at the state and metropolitan levels (U.S. Bureau of Economic Analysis, 2013). In general, the direct effects of a transportation improvement on value added can be calculated on the basis of two considerations: (1) the cost savings to affected businesses (in obtaining delivered parts and materials, paying workers, transporting workers and/or shipping products to customers), and (2) the increase in net income obtained from expanded output (enabled by the lifting of prior constraints). Additional net income associated with increased (domestic or global) trade competitiveness also can be assessed with the use of economic models.

Capital productivity is a more difficult concept to implement for assessing transportation project impacts, because there is limited baseline information available to measure the level of capital investment associated with different industries and products at a local or regional level in the United States. At the national level, this information is available from the national income and product accounts, produced for the United States by the Bureau of Economic Analysis. But the cost of land, buildings, and equipment is known to differ among regions, and it would be very resource-intensive for a transportation agency to try to adjust those values for specific states or regions.

Multi-factor productivity, also known as total factor productivity, accounts for the full impacts on use of all economic inputs (capital, labor, etc.) and for substitution between them. However, difficulties exist when attempting to directly measure multi-factor productivity as part of the evaluation of an individual transportation project. First and foremost, the units of multi-factor productivity (ratios) are not particularly meaningful to decision makers or the general public, which means that changes in the metric are hard to interpret. Specifically, it is not clear if a given change in the productivity ratio represents a large or small change. Second, there is a need to have a baseline measure of multi-factor productivity for businesses affected by a given transportation investment. Such a measure can be resource-intensive to derive.

In addition, there is a lack of empirical evidence on how multi-factor productivity changes in response to changes in transportation system performance features (such as speed, reliability, or accessibility). At the macroeconomic level, there was a flurry of empirical research on the relationship of transportation investment to GDP and multi-factor productivity that ran from Aschauer (1989) to Mamuneas and Nadiri (2006). The output of this research was directed at answering policy questions related to the contribution of public-sector expenditures to economic growth. It does not transfer well to the evaluation of incremental changes in transportation networks, where system performance measures are the key variables affected by the investment—rather than proxies such as lane-miles or investment costs as used in macroeconomic studies.

Direct measurement of change in multi-factor productivity is therefore not practical for the evaluation of most individual transportation projects. It is, however, possible to assess the effects of a transportation project on the labor productivity of businesses that are directly affected by that project. This report presents steps needed to calculate that metric. If the effect is large enough to warrant the additional cost and effort, then a regional economic simulation and forecasting model can be used to estimate broader macroeconomic productivity impacts (resulting from effects of shifts in the supply, demand, and cost of labor, capital, and transportation services, and their activity locations). That option is also discussed later in this report.

1.5 State of Research and Practice

State of Research

This is an opportune time for transportation planning and operating agencies to consider productivity as part of the investment decision-making process, because a variety of research studies have been conducted in recent years to establish a base of information on the relationship of transportation projects to productivity impacts. For instance, in the United States, there has been substantial research on the roles of travel time reliability and intermodal connectivity in affecting logistics costs and supply chain productivity. There also has been research on the role of same-day delivery market access in generating scale economies for distribution channels, as well as manufacturing clusters that further increase productivity. Following the United Kingdom (UK) lead, there is a growing base of U.S. and international research on the measurement of urban market access, and its statistical relationship with agglomeration effects that generate productivity gains in the economy.

These lines of research are fully reviewed in *NCHRP Project 02-24: Literature Review and Stakeholder Perspectives* (EDR Group et al., 2012). The following two observations may be drawn from it:

- On the positive side, the body of recent research is generating a growing range of metrics and tools for representing changes in market access, reliability, and connectivity, as well as economic responses and productivity impacts. We can leverage that information to now generate calculations of productivity impacts that were not possible a decade ago. This report specifically draws on research findings to show how projects can now be assessed in terms of productivity impact, and how that information can be used in prioritization and investment decision making.
- On the negative side, there is a need for significant further research to distinguish (1) different forms of access, reliability, and connectivity, and (2) how different business sectors are affected by them.

  For instance, the accessibility research has largely focused on measures of economic mass at an urban scale and provides little insight for intercity passenger travel or inter-regional supply chain movements. There is also a need for more empirical research on agglomeration to distinguish localization (clustering) effects from urbanization (market scale) effects, as they apply to different industries. Although the reliability research has been substantial, available information on inventory and stocking impacts on various industries (a key element of productivity) is still limited.

State of Practice

Although much work remains to ensure the consistent practical application of the theory to the assessment of transportation projects and programs, U.S. states and foreign nations have already started adopting productivity elements into their project evaluation and prioritization practices. The research team conducted interviews to document the extent to which productivity elements are now being measured and considered in transportation project prioritization. Detailed discussion on the state of practice is provided in the *NCHRP Project 02-24: Literature Review and Stakeholder Perspectives* (EDR Group et al., 2012).

Overall, the literature review and interviews showed that a growing number of U.S. states have adopted methods for rating competing projects that include productivity and related economic growth elements as factors in the decision process. Some explicitly use measures of market access, reliability, and connectivity—drivers of productivity change—in their project ratings. Others account for productivity through an estimate of GDP or GRP growth, generated by a regional economic impact model that also accounts for market access, intermodal connectivity, and/or reliability changes. The various decision-support approaches that are in current use are discussed in the next chapter (Section 2.2).

The review also discusses the United Kingdom's (UK) formal national approach to incorporating economic productivity in the assessment of transportation projects. The UK approach is highly codified; specific guidance is provided online in Transport Appraisal Guidance called WebTAG. Wider economic benefits, particularly agglomeration economies, are now routinely included as additional benefits in benefit-cost analyses. The UK also includes impact on economic growth as a factor in its multi-criteria assessment of the broader business case for transportation investments—recognizing that productivity increases lead to aggregate growth in value added (affecting GDP or GRP).

Beyond the U.S. and UK, other countries also have adopted the approach of incorporating productivity impacts. The Netherlands has a long tradition of using project rating techniques in decision making, and its system now recognizes wider economic effects including agglomeration and reliability impacts. New Zealand and Australia also have begun to incorporate wider economic effects into their benefit-cost methodologies.

CHAPTER 2

Using Productivity Information to Support Transportation Decisions

This chapter presents the recommended approach for productivity impact calculation and criteria for determining whether the evaluation of productivity effects is relevant for a given type of project. It also discusses how productivity effects can be incorporated into the major measurement methods used for decision making: multi-criteria analysis, economic impact analysis, and benefit-cost analysis.

2.1 Defining the Elements of Productivity Impacts

The discussion in Chapter 1 established that there are several ways to view and measure productivity. It concluded that the most practical measure for assessing the impact of an individual project is in terms of productivity per worker. It concluded that multi-factor productivity is too difficult to routinely calculate for project impact evaluation, although this can be done through some regional economic simulation and forecasting models.

Chapter 1 also established that it is possible to identify effects of transportation projects on the achievable output or cost of operation for directly affected firms. It grouped those effects into four categories of transportation impact measurement—traditionally measured transportation cost effects, plus three impact categories that are not traditionally part of the standard traveler benefit calculations: reliability effects, accessibility (agglomerations) effects, and intermodal connectivity effects.

Taken together, this leads to a general formula that is the basis for the instructions provided in detail in Chapter 3. The formula decomposes the effect of transportation investments on productivity into (1) impact elements that can lead to productivity impacts, and (2) broader measures of overall direct effects on productivity impacts.

Δ Productivity impact elements (for directly affected firms)

Δ Σ Value Added *(for firms that rely on the affected transportation facilities for worker or product transport)*
= function of changes in transportation factors including:

- Δ Travel time delay cost (A)
- Δ Vehicle operating cost (A)
- Δ Vehicle collision cost (A)
- Δ Reliability (B)
- Δ Market access (B)
- Δ Intermodal connectivity (B)

} *For freight delivery, plus service delivery and other business-related worker travel*

where

Δ = *change in*
Σ = *sum of*
(A) forms of user benefit that are covered in standard traveler benefit analysis
(B) other transportation impacts that also affect productivity

The formula for productivity impact elements differs from the concept of social welfare benefit that is used in benefit-cost analysis in that it counts only effects that reduce business operating costs or increase business output (revenue) in a given region. That includes direct business savings associated with changes in vehicle operating costs and worker time for truck freight travel and car business travel. It also can include savings in commuting costs (normally considered to be borne by drivers) to the extent that employers are paying a wage premium or direct subsidies to partially compensate workers for excess travel time and expenses. (This issue is discussed in detail in Appendix A2.)

The productivity elements intentionally do not include the willingness-to-pay value of personal time savings and all household cost savings (which may be redirected to other forms of spending, but will not affect business productivity), as well as the value of consumer surplus, unless there is some ultimate impact on business costs. Safety impacts are typically not counted except to the extent that they affect business expenses for fleet vehicle repairs or actually lead to changes in insurance costs for personal injury. On the other hand, wider benefits associated with reliability, market access, and intermodal connectivity are added.

The productivity elements can lead, through a variety of mechanisms, to direct changes in business operating cost, as well as broader effects on business efficiency. The formula is as follows:

Δ Direct productivity effect (for an entire region or study area)

= (Δ Σ Value added due to direct cost savings for directly affected firms
+ Δ Σ Value added due to enabling of business reorganization and technology adoption
+ Δ Σ Value added due to agglomeration effects related to increased market access (allowing more firms to make use of the facility and hence be directly affected by it))

. . . which is then expressed per worker, wage, or investment dollar

Note: If productivity increases are localized, and if there are supply side constraints on the availability of labor, land, or capital inputs to the production process, then it is possible that value added growth could be reduced as other economic activities may be crowded out. However, a regional economic model is normally required to make those adjustments.

2.2 Determining the Relevancy of Productivity Impacts

The elements of productivity impact measurement that are itemized in the preceding formulas are useful because they also enable guidance regarding when it is useful to calculate productivity impacts. After all, not all transportation projects will have additional productivity impacts to be measured. In fact, many will not. Projects that affect productivity in the economy are those that affect the unit cost of business operations—changing the amount of labor or capital required to produce a given product, or the volume of product that can be produced for a given set of labor and capital resources.

It is useful to classify transportation improvement projects into three categories: (1) those that typically have no productivity impact, (2) those that have productivity impacts, but they are already captured by current benefit measurement practices, and (3) those that have additional productivity impacts beyond those already captured by current practices. Each category is explained further below.

1. **Projects that have essentially no productivity impact.** This tends to include projects that are focused on addressing safety factors, environmental factors, social or community cohesion factors, or primarily affect recreational and personal trips rather than business-related travel. In each of these cases, there may be clear benefits to transportation system users and/or affected parties in the surrounding area, and those benefits may be assigned a dollar value (based on willingness-to-pay surveys). In some cases, they may affect the economy by shifting the spending patterns of households or the patterns of revenue among businesses (for example, situations where local businesses stand to gain sales from expanded tourism coming into the affected area). However, these types of projects typically have no direct effect on the unit cost of production for any sector in the economy, and hence there is no productivity change in the economy. Examples of this first category of projects are shown in Table 2-1, Part A.
2. **Projects that have cost efficiency effects but have no wider effects**. This tends to include projects or policies that enable business-related travel with higher capacity vehicles, higher frequency operations, reduced vehicle operating costs, or the ability of long-distance trips to bypass local bottlenecks. In each of these cases, there are likely to be direct cost savings to transportation service operators and/or business-related users. By directly reducing capital costs and directly increasing the efficiency of vehicle operations, these types of projects effectively enable more transportation activity per worker, which represents enhanced labor productivity. By reducing the expense per passenger or per ton of freight, they may also enhance capital productivity. However, both of those types of cost savings can already be captured by traditional user benefit analysis. So, unless there are further reliability, accessibility, or connectivity effects (which are not necessarily caused by these types of projects), there may not be any further factors driving productivity change beyond those already measurable by traditional methods. Examples of this second category of projects are shown in Table 2-1, Part B.
3. **Projects with broader impacts on reliability, market access, or intermodal connectivity that are not being captured by standard traveler benefit metrics.** These are the projects for which this report will be most useful, as inclusion of their broader productivity effects (in addition to currently measured benefits) could lead to a change in project ranking or funding decisions. What sets them apart is neither the project size nor the magnitude of travel time or cost changes, but the existence of particularly notable impacts on (1) enhancing reliability (i.e., reducing travel time variability) in congested areas, (2) enhancing the breadth of interzonal access across a region, or (3) enhancing access to, or connecting services at, a specific intermodal (air, marine, or rail) terminal. Table 2-1, Part C, shows the types of projects that tend to fall into this category. There are additional rules for screening projects in this class, to isolate those that are most likely to have productivity impacts; those rules are discussed later in Chapter 3.

Implications for the practical use of this report. This three-way categorization in Table 2-1 is a first step in distinguishing projects that can, and should, be evaluated in terms of productivity impacts. It enables the following observations:

- Projects in Categories A, B, or C can be evaluated and ranked using either the multi-criteria rating or benefit-cost methods (discussed in Section 2.3). However, only Categories B and C are likely to have productivity effects that can be distinguished.
- Technically, the Chapter 3 productivity calculation steps can be applied to projects in both Categories B and C. However, results for Category B will be similar to numbers generated by standard traveler benefit methods, so there is a screening step that recommends further analysis only for a subset of projects in Category C.

Table 2-1. Classification of transportation projects by form of productivity impact.

A. Projects that typically have little or no productivity effects

Projects that Address Social/Environmental/Safety Issues and Personal Recreation Travel*
• **Redesign to enhance safety** — improve existing routes by changes in guard rails, shoulders, geometrics, visual obstructions, surface traction, lighting, signs; • **Enhance to address environmental factors** (noise, air, visual impacts) — sound barrier walls, berms, vegetation in buffer zones, or relocation of facilities to reduce adverse effects; • **Redesign to address social cohesion factors** — underpasses or decking of right-of-way trenches to enable access paths from neighborhoods to schools, parks, community facilities; • **Redesign to reduce detours or closures due to natural occurrences —** road or rail corridor drainage, elevation and barrier projects to minimize effects of landslides and floods; • **Special purpose road and rail routes** — new or enhanced routes to better access tourism and recreational destinations.

B. Projects with productivity benefits driven by traditionally measured user benefits

Projects that can Reduce Time Cost for Business-Related Travel*
• **Speed improvement on links** — upgrade roads or rail tracks to enable faster vehicle speeds; • **Bypass links** — add special lanes, tracks, or modal route separation (including busways), to enable long-distance and pass-through vehicles to avoid local bottlenecks; • **Connector links** — add special truck access routes for industrial parks, border crossings, intermodal rail, air freight, or marine terminals; • **Higher capacity vehicles** — upgrade roadway, rail line, airport runway, or structure (road or rail bridge, overpass or tunnel) to increase allowable vehicle size and weight; • **Higher frequency operations** — implement positive train control, enhanced air traffic control, or other technologies that reduce minimum vehicle spacing; • **Dwell time reduction at nodes** — convert road intersection to limited access interchange, add turning lanes, optimize signal timing, implement in-road tolling, upgrade processing speed at bus terminal, rail terminal, airport, or marine port.

C. Projects with wider business benefits not all captured by traditional benefit assessment

C1. Projects that can Enhance Reliability (and Reduce Time Cost) for Business-Related Travel*
• **Reduction in peak period congestion bottlenecks** — add highway lanes, rail tracks, or airport gates; expand truck or rail loading facilities; expand dock capacity at seaports; • **Reduction in incidence of interfering activities** — construct road or rail overpass or underpass to reduce grade crossings; replace drawbridge with high-clearance bridge; construct alternative routes for route affected by activity at sports/entertainment venues; • **Reduction in incidence of collisions** — implement design improvements to enhance safety for freight movements via roads, rail lines, or ship channels.
C2. Projects that Enhance Regional Accessibility (and Reduce Time Cost) for Business Travel*
• **New (or substantially upgraded) access routes between communities in a region** — add a new highway route, busway route, rail transit route, or ferry route that enlarges the market for travel to/from endpoints served (and hence induces more travel between those points); • **Enhanced service frequency between communities in a region** — implement high-speed and reduced stop (express) services for scheduled bus, rail, or ferry services.
C3. Projects that Enhance Intermodal Connectivity (and Reduce Time Cost) for Business Travel*
• **Enhanced ground access to intermodal terminal** — implement new or improved highway route or rail transit service for ground access airport, train station, or ferry terminal; • **Expanded connecting services at intermodal terminal** — add number of destinations served, or frequency/quality of scheduled services — for intercity air/rail/ferry transportation services available at airport, train station, or ferry terminal.

*Note: Business travel includes freight deliveries and worker travel to deliver services or attend business meetings — the cost of which is typically paid by businesses. Commuting travel may be included in productivity measurement when the affected trips are predominantly to/from an employment cluster or center where businesses are paying a wage premium to workers in compensation for the long travel time, great delay, or high expense associated with working there. That applies most typically for travel to large urban centers with congested access and high parking cost, or to locations at the fringe of a labor market area, as discussed in Appendix A2.

- Limitations of currently available research and analysis tools mean that productivity calculation can be fully carried out only for a subset of projects in Category C. Currently available tools (described in Chapter 5) are applicable primarily for urban or regional road and rail projects, and ground access to intermodal terminals or ports. Although the general methodology can be applied to other types of projects (e.g., intercity ground transportation as well as air and marine transportation projects), those applications will require more customized analysis.

Screening process—The magnitude of project impacts on productivity, beyond that normally associated with standard traveler benefits, will depend on the magnitude of the Category C factors—reliability, accessibility, and intermodal connectivity. Chapter 3's first screening step uses information regarding the project and its context in order to identify projects that are likely to create significant additional productivity impacts.

2.3 Incorporating Productivity Impacts into Project Evaluation

For those types of projects that can generate productivity impacts, it will be important to be sure that the productivity effects are measured and portrayed in a form that is useful for decision analysis. Table 2-2 shows examples of how productivity impacts can be used in a variety of decision processes that involve some form of project rating or prioritization.

2.3.1 Available Rating Methods for Project Prioritization

Every U.S. state DOT and MPO has some process for evaluating and prioritizing requests for enhancement of individual roads and rail transportation facilities. These processes can be classified into three primary methods that are commonly used in Europe and elsewhere overseas.

Table 2-2. Relevance of productivity impacts to transportation decisions.

Decision Process	Key Questions to Address	Typical Sources of Productivity	Scale of Analysis
Prioritization or Programming (Project Tradeoffs)	Productivity gain as a component of overall benefit or impact of a specific project relative to another project	Reduced delay; improved reliability and connectivity	Region or statewide analysis
Programmatic Investment Strategies	Productivity as a component of overall benefit or impact of all projects in a program relative to other programs	Improved regional accessibility; systemwide reliability improvement across modes	Regional, local, or statewide networks (often multimodal)
Corridor or Small-Area Plans	Productivity gain as a feature distinguishing one project alternative from the others	Improved accessibility to, or from, a specific location	Key access links and key business nodes within a study area
Responding to Stakeholder Issues	Productivity gain as a rationale for investing in transportation improvements	Improved access of a location to workers; improved reliability with less delay	Key access links and business nodes within a study area

Productivity impact measures can be used in all three of these methods, which are summarized as follows:

- **Multi-Criteria Analysis (MCA)** involves scoring projects by measuring or assessing a set of qualitative and quantitative impact factors, which may include productivity-related factors. Weights are applied to each factor to produce an overall total score for each project. A variant is goal-based rating (GBR), which avoids formal scoring but still considers how each project rates relative to a set of identified goals.
- **Benefit-Cost Analysis (BCA)** involves calculating the money value of all traveler benefits and all other social benefits. A transportation system change may have positive or negative effects on both classes of benefit, including productivity changes. Outside the United States, BCA is often referred to as cost-benefit analysis (CBA).
- **Economic Impact Analysis (EIA)** involves calculating the impact on growth of jobs and income in the economy. There may be direct effects on the productivity of firms or industries in given areas that use or rely on the transportation system, which drive the calculation of broader impacts on the economy in EIA models, and ultimately lead to wider measures of macroeconomic productivity change.

Each of these project rating methods has a different set of issues and solutions regarding the use of productivity impact measures.

2.3.2 Incorporating Productivity Factors into Multi-Criteria Analysis (MCA)

Current State of MCA Practice—The most common processes used by state DOTs for prioritizing transportation projects are rating systems—either multi-criteria analysis (which scores proposed projects, based on a set of rating criteria and a set of weights applied to them), or goal-based ratings (which consider a set of goal criteria without calculating formal scores). The rating criteria typically include transportation system performance indicators, along with some aspect of equity, economic development impact, environmental sustainability, and compatibility with social/community goals.

Measures of change in productivity outcomes or productivity elements can be used directly in MCA as indicators of economic development impact. Table 2-3 shows examples of economic development indicators now in use as rating criteria for project prioritization in seven state DOTs.

It shows that none of the six states currently include total statewide productivity impact as a rating factor. The practice that comes closest is Wisconsin DOT, which does have a qualitative rating factor called "support freight productivity." Missouri and Oregon also have qualitative factors recognizing projects that enhance freight movement.

Yet, all of the states have rating factors that capture efficiency effects, and all have some additional factors that represent drivers of productivity—measures that lead to reliability, market access, and/or connectivity change. However, these rating factors generally pertain to all trips and do not distinguish between impacts on business-related travel (which drives productivity) and impacts on non-business travel (which does not affect productivity).

Finally, it is notable that several states also have rating factors reflecting overall economic growth impacts in terms of jobs or statewide GDP (gross domestic product) or GRP (gross regional product). These outcome factors are typically results of increased productivity.

Recommendation for Incorporating Productivity Measurement into MCA—To truly capture productivity impacts in project impact rating systems such as MCA, it is necessary to modify the set of rating factors so that they are shifted from transportation system efficiency metrics to

Table 2-3. Use of productivity-related effects in multi-criteria rating (seven state examples).

Existing Criteria (Rating Factor)	Corresponding Productivity-Related Metric
• Freight productivity (WI)	Overall Productivity
• Travel time and cost reduction (OH, WI, NC) • LOS improvement (WI) • User benefit (WS, KS)	Element: Travel Efficiency (Standard Traveler Benefit)
• Volume/capacity (OH, NC, OR) • Congestion relief (MO)	Element: Reliability
• Promotes freight movement (MO, OR) • Promotes exports from state (WI)	Element: Accessibility
• Multimodal impact (OH) • Intermodal connectivity (MO) • Connections to network (WI)	Element: Connectivity
• Job growth (OH, WI) • GDP growth (NC, KS)	Outcome of Productivity

Note: OH=Ohio DOT, OR=Oregon DOT, MO=Missouri DOT, NC=North Carolina DOT, WI=Wisconsin DOT, WS=Washington State DOT, KS=Kansas DOT

productivity-related factors. The productivity factors can be calculated and portrayed at any of the three following levels:

- Measure of overall labor productivity change—calculating direct project effects on labor productivity in the study area. This is the most straightforward way to incorporate productivity into project rating. Inclusion of this measure will give weight and priority to projects that add the most to regional income and job creation.
- Measure of input elements that lead to productivity change—using metrics that isolate effects on freight or all business trips and express impacts in terms of change in (1) reliability (reduction in non-recurring delay), (2) labor force access or truck delivery market access (depending on the type of project), and/or (3) connectivity to intermodal terminals. This is a less direct way to recognize productivity effects in decision making, but it may be desired when there is policy interest in specific goals.
- Measure of outcomes generated because of productivity change—using overall economic growth measures generated by regional economic models that explicitly account for all three of the input elements listed in the prior bullet. Depending on the input data provided for the economic model, this approach could provide a more precise and complete calculation of productivity and income growth effects.

Chapter 3 provides instructions for deriving all three of these types of metrics.

2.3.3 Incorporating Productivity Elements into BCA (Benefit-Cost Analysis)

Current State of BCA Practice—Many states regularly conduct some form of user benefit analysis or BCA to assess impacts of proposed projects, as part of their prioritization processes. However, nearly all of those analyses stick to the AASHTO Red Book definitions that primarily calculate the value of travel time savings, vehicle operating cost savings, and crash reduction impacts that basically represent the benefit to travelers and transportation system efficiency. Few states incorporate the other productivity elements discussed in this report—benefits associated with greater reliability, accessibility (agglomeration impact), and intermodal connectivity. The reason for this is not that there is any doubt about the existence of such benefits, but rather, there are questions about how to measure them. This report provides information to help address those issues and enable broader benefit calculations.

Recommendation for Incorporating Productivity Factors into BCA—To capture productivity impacts in BCA calculations for individual transportation projects, it is necessary to add additional elements of benefit. Productivity cannot by itself be added to BCA because a portion of productivity gain associated with cost savings is already included in traditional BCA. So it is instead necessary to modify current BCA methods to include the heretofore unmeasured portion of business benefits associated with improved reliability, accessibility (agglomeration impact), and intermodal connectivity. This involves the following three actions:

- Change the definition of user. Although the standard practice has been to measure costs for those driving or riding vehicles, this view is not appropriate for freight since it is the shippers and consignees (receivers) who pay for freight transportation service and hence are the actual users of the transportation system, rather than the truck drivers or freight carriers.

  Adopting this view allows for the inclusion of logistics costs relating to added labor and overtime cost incurred when loading dock workers have to wait for delayed shipments. It allows for inclusion of added costs of freight transfers between vehicles, time cost of freight inventory in vehicles, and added costs for relief drivers that become necessary when there are road/bridge use restrictions or long delays.
- Incorporate reliability as a benefit category. Change in average (mean) travel time and the associated valuation of it is part of standard BCA procedures. However, accounting for the value of reliability enhancement (variation around the mean) is not a part of standard BCA procedures, although there is a strong theoretical case building for its inclusion in BCA calculations.

  The core issue is that variation in travel time caused by traffic incidents tends to grow exponentially in both likelihood and severity as congestion worsens. Unpredictability also can occur in the timing of road closings when trains pass through at-grade rail crossings, and when major road reconstruction projects lead to intermittent and sporadic road closings and detours.

  Businesses that depend on worker travel and freight deliveries commonly pad their schedules (i.e., build in extra buffer time) to enable them to be on-time even in the event of such occurrences. Of course, that can bring costs in terms of added labor time, added inventory requirements, and reduced number of deliveries scheduled per vehicle per day. Transportation projects that improve reliability can thus reap the benefits of avoiding those added labor and capital costs. At a certain point, reliability improvements can enable new supply chain technologies.
- Include market access and connectivity effects. Changes in speeds, distances, and travel times also can increase the effective density, range, and size of a firm's labor market and customer delivery market. That can enable product and service firms to gain economies of scale (changes in business efficiency and unit cost) as well as other agglomeration economies associated with urbanization and localization benefits that can affect business organization and operations.

  These economic gains associated with broader market access are all in addition to benefits associated with induced trips. Although induced trips can include some access-related trips (for instance, travelers seeking job opportunities in new markets that were previously considered inaccessible), business scale economies and other agglomeration benefits are above and beyond the benefits to induced travelers.

There are instructions for incorporating all of these additional categories of benefit into productivity calculations in Chapter 3. Some of those instructions also build on available tools for assessing wider economic benefits that are summarized in Chapter 5.

2.3.4 Measuring Productivity in EIA (Economic Impact Analysis)

Current State of EIA Practice—Regional economic impact forecasting models are available in the United States, Canada, and other nations to estimate the macroeconomic impacts of programs or projects that affect productivity. These models forecast how changes in business costs and accessibility patterns lead to broader effects on regional employment, income, and business output. The "region" scale of these models may vary from a city to a nation.

To incorporate productivity effects in EIA, it is necessary to use a dynamic economic impact forecasting model that can estimate impacts of business cost and access changes on business investment and trade, as well as changes in the labor supply and demand that can affect relative wage rates. Static input-output models do not forecast impacts of cost or access changes, and thus cannot be used alone to generate transportation project impacts. A spatial economic model embedded within a land-use transportation modeling system may forecast changes in spatial patterns of economic activity within a region, but such models typically assume a fixed forecast of regional economic growth.

A growing number of state DOTs and MPOs are now regularly conducting EIAs to assess impacts of proposed transportation projects on economic growth, using a dynamic economic impact forecasting model. Some do so as part of a formal prioritization process, and include job or GDP impacts as a factor in project ratings (e.g., Wisconsin DOT, North Carolina DOT, Kansas DOT, and Ohio DOT). Many others apply EIA for major projects, to further support a business case assessment or environmental impact assessment process.

Treatment of Productivity Impacts in EIA—It is notable that regional macroeconomic impact models treat business and household cost savings differently. They treat savings in transportation costs for business-related travel as a reduction in business operating cost (which generates productivity gain), while changes in transportation costs for households are treated as shifts in the pattern of consumer spending (which can affect the mix of industry sales, but will not affect productivity). EIA models thus recognize productivity improvement as the primary basis for real income growth. This is different from BCA, which equally counts both business cost savings and household cost savings as benefits.

Regional economic impact forecasting models also estimate indirect effects on economic growth within a region. That includes effects of relative cost changes that lead to spatial and business sector shifts in trade flows, investment flows and business locations. These further impacts are not counted in BCA, though they may affect multi-factor productivity. This is most likely to be the case if a transportation project is significant enough to cause shifts in trade patterns or in relative prices for labor or capital goods. In those situations, productivity may change as there are changes in the valuation of the mix of labor, capital, and transportation services used to produce goods.

Recommendation for Incorporating Productivity Factors into EIA—Regional economic impact forecasting models can directly build upon the productivity impact instructions described in Chapter 3, and they may be used to generate estimates of broader economic impacts for designated regions.

The types of productivity-related factors that may be input into regional economic impact models are shown in Table 2-4. Major regional impact modeling systems such as REMI TranSight and TREDIS have inputs for exogenous changes in business cost savings and effective market access (although they differ in the form and detail of those inputs). Those changes can be calculated through the use of the Chapter 3 instructions. Depending on the economic model, further changes in reliability and connectivity may be input as either cost and output changes, or directly calculated via procedures that are built into the model system. Further information on this topic is provided in Section 5.6.

Table 2-4. Productivity-related inputs to regional economic impact models.

Impact Element	Metric (input to economic impact model)
Transportation Expense (Cost)	Business $ Cost Savings (or VMT and VHT change)
Reliability	Business $ Cost Savings (or extent of high V/C on highways)
Intermodal Connectivity	Business $ Cost Savings or Output Growth (or intermodal terminal access time and service ratings)
Access: Customer Delivery Market	Effective Size, Distance, or Density of Delivery Market
Access: Labor Market	Effective Size, Distance, or Density of Labor Market

Regional economic models can substitute for, and improve upon, some of the available tools and calculation processes described in Chapter 3. This can be desirable because regional economic models typically have information regarding how a project would affect specific industries within the study area economy. These models are able to allocate time, cost, and access benefits among local industries by building upon datasets that contain employment breakdowns by industry and occupation, and freight shipment breakdowns by industry and commodity. That enables use of industry-specific impact response elasticities instead of the more general response factors provided in Chapter 3. (The more general factors are necessary in the instructions because those instructions are designed for situations where a regional economic model is not available to the analyst.)

The results of a regional economic model may be used to help inform project prioritization processes, and may be included in project rating systems. However, economic impact models focus just on business impacts, and hence cannot fully substitute for BCA or MCA rating methods that also incorporate information on broader societal benefits and non-business travel benefits.

CHAPTER 3

Guidance: Steps to Assess Productivity Impacts

This chapter provides detailed instructions for carrying out the six steps required to assess productivity impacts of transportation projects. The instructions are necessarily detailed and technical; readers may note that the actual calculations can be viewed more simply via the three case study examples that are presented in Chapter 4.

3.1 Overall Framework and Sequence of Steps

This guidance was developed with four key methodology features:

- **Allow for flexible use.** Some agencies may wish to utilize the guidance to calculate productivity gain specifically for the set of directly affected firms. For example, an analyst may wish to assess the business productivity benefits of a route that predominantly provides access to an industrial park, intermodal rail terminal, or air freight facility. Some agencies may wish to use that information to derive a broader estimate of state or regional macroeconomic impact, using a regional economic simulation model. Others may wish to just pick out the elements of broader impact that are not already captured in existing benefit-cost analysis methods. Any of these approaches may be used for prioritizing, programming, or planning processes. There should be the flexibility that steps may be skipped or followed, as appropriate, to allow for all of these uses.
- **Provide a screening process to reduce user burden.** While the method for calculating productivity impacts is designed to be usable by DOTs and MPOs across North America, it is also clear that it involves significant time and resources to assemble and process the required data. For that reason, it is worthwhile to screen out those projects or situations where the extra effort may not be worthwhile.

  Two types of situations should be screened out. The first is where the project is unlikely to have productivity implications much beyond what is already covered by widely used standard travel benefit analysis. The other is situations in which the effects of calculating further productivity benefits are likely to be negligible or too small to warrant the extra effort.
- **Use the necessary tools.** Even for projects where analysis of productivity impacts is warranted, it is important to identify the type of project, the corresponding types of transportation system changes that are applicable, and the corresponding types of productivity impact tools that are relevant for use. In other words, depending on the type of project, traditional user cost impact, reliability impact, accessibility impact, or intermodal connectivity impact tools may be applicable. It is usually not necessary to involve all of those impact assessment tools, and if that is done then extra effort may be necessary to adjust for double counting.

- **Allow for different modeling capabilities.** The data assembly and calculation processes must be applicable for transportation agencies spanning a wide range of different transportation and economic modeling capabilities. It is recognized that some transportation agencies may have sophisticated travel demand, highway network, economic, and land-use models. Others may have none of these models, and instead rely on engineering estimates and sketch planning analysis methods. The analysis tools discussed must be useful for both types of situations, as a means to calculate time, cost, access, reliability, and connectivity effects.

Six prescriptive steps address the preceding requirements and provide a means for measuring each of the previously cited transportation factors and components that go into the productivity impact calculation. This sequence allows the analyst to estimate intermediate transportation factors, turn these into productivity elements, and then use those results to estimate broader productivity impacts. The steps are as follows:

- *Step 1: Screen to Assess the Need to Assess Productivity Impacts*—Assess whether productivity analysis is appropriate for a given project, and apply a Screening Decision Table to determine whether available analysis tools can be utilized.
- *Step 2: Select Applicable Tools*—Use Step 1 information with an Analysis Tool Selection Table, to determine the types of transportation impact factors that need to be analyzed, and analysis tools available for measuring them.
- *Step 3: Measure Standard Traveler Benefits*—Assemble transportation data and calculate direct effect on travel-related business costs.
- *Step 4: Calculate Wider Transportation Benefits*—Use data from Step 3 with tools from Step 2 to calculate reliability, market access or intermodal connectivity impact.
- *Step 5: Calculate Productivity Elements*—Apply coefficients and elasticities to Step 4 results to calculate impacts on cost or output scale for directly affected businesses.
- *Step 6: Present and Interpret Productivity Results*—Use results of Step 5 to calculate productivity impact and use results in project evaluation processes: MCA, BCA, EIA or "stand-alone presentation."

Each step lays out its logic, in terms of objective and intended use, the procedure involved in taking input information and producing a result, and the data sources and tools that are required or recommended for use.

3.2 Step 1—Screen for Productivity Impacts

In this step, the analyst collects basic information on the type of project being considered and the setting in which it will be implemented. Using this information, the analyst is able to determine the likelihood of the project producing economic productivity impacts and whether the inclusion of these impacts in the evaluation is worthwhile. As part of the initial screening, the analyst identifies the forms of productivity impact that are likely to occur for the specific project type and setting. This allows the analyst to decide what forms of productivity impact to include and the types of tools to use in the analysis.

The process for Step 1 has the following two parts:

- 1-A: Assemble basic information about the project to fill in a *Project Classification Form*, and
- 1-B: Apply a *Screening Decision Table* to identify the likely types of productivity impact to be calculated in subsequent steps.

Step 1-A: Assemble Basic Information about the Project

The first action in Step 1 is to assemble basic project information by filling in the Project Classification Form (Figure 3-1). The form asks for information regarding the facility type, project objective, project impact area, and trip purposes supported by the project. This information will be used to determine the applicability of productivity impact analysis.

This information should be readily available from project planning documents, such as project study reports, transportation planning reports, and environmental impact reports. While the names and types of reports vary by state and agency, most projects will have some kind of planning document that establishes the purpose and need of a project. In early project screening, a planning document may not be available. In that case, an analyst's knowledge about the project can be sufficient to fill in the checklist.

Data Sources and Instructions for Use of the Project Classification Form

The following information can be used when filling out the Project Classification Form.

Project Name: This information is not needed for analysis; it is for identification purposes.

Project Facility Type: The analyst classifies the transportation facility that is proposed for the improvement, in terms of the role that the facility plays in the transportation network. The analyst can select multiple facility types for a given project.

The *facility use orientation* refers to whether the facility is oriented toward serving freight movement, passenger use, or both. In the case of public transportation, rail, marine, or airport

Project Name ____ *(fill in for your own use)*

Project Facility Type *(check one or more, as applicable)*

Corridor or Line Type:
☐ Highway/Road ☐ Dedicated Busway ☐ Rail Line

Intermodal Terminal Type:
☐ Airport ☐ Marine Port ☐ Rail Freight ☐ Passenger (Bus or Rail) ☐ Maintenance Facility

Use Orientation:
☐ Passenger ☐ Freight ☐ Both Passenger and Freight

Dominant Project Objective(s) *(check one or more)*
☐ Congestion/Reliability ☐ Capacity/Future Growth ☐ Travel Time (Distance, Speed)
☐ Service Frequency ☐ Closure/Detour Reduction ☐ Intermodal Connectivity
☐ Metro Market Access ☐ Business Site Access ☐ Access to Isolated Rural Community
☐ Safety ☐ Preservation or Rehabilitation ☐ Quality of Life

Primary Project Impact Area *(check one or more)*
☐ Urban/Metro Area ☐ Rural Area ☐ Intercity Connection ☐ Multi-State Region
☐ National/International Gateway

Trip Purposes Served (Above Average): *(check one or more)*
☐ Freight ☐ Commuting ☐ Business Travel ☐ Recr./Tourism ☐ Mix (no trip type is above avg.)

Figure 3-1. Project classification form.

facilities, this may be obvious given the type of corridor/line or terminal, and its location. In the case of roadway projects, traffic counts may be used to identify whether truck volumes are substantially above 4 percent of all vehicles. Sources for roadway data include

- Traffic count (AADT) data—available for individual highways across the United States in the Highway Performance Monitoring System (HPMS), http://www.fhwa.dot.gov/policyinformation/hpms/states.cfm, and
- Truck and total vehicle traffic counts for major highways—available in the Freight Analysis Framework (FAF) database, http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/netwkdbflow.

Dominant Project Objective(s): The checklist includes overlapping categories from which the analyst may select multiple categories. Definitions for these goals are provided below. Further information on matching specific types of projects to objectives was provided in Table 2-1, which appeared earlier in Chapter 2 of this report.

Mobility-related objectives

- *Congestion/Reliability* applies to projects that address congestion (high volume/capacity) and associated delay conditions.
- *Capacity/Future Growth* applies to projects that address future demand growth (and future congestion concerns).
- *Travel Time* applies to projects that provide a shorter or faster path between areas.
- *Service Frequency* applies to enhancement of service for non-highway modes, such as transit, aviation, or passenger rail.
- *Closure/Detour Reduction* applies to projects that address sporadic delays at rail crossings, or sporadic road closings and detours in areas prone to flooding, landslides, or snow slides.

Access-related objectives

- *Metro Market Access* applies to projects enlarging effective population and labor markets.
- *Business Access* applies to access roads and interchanges that improve access to existing business parks and centers, and enable development of new business centers.
- *Rural Community Access* applies to projects that enhance access to remote rural areas and small communities.
- *Intermodal Connectivity* applies to projects that reduce time to access intermodal passenger or freight terminal, or improves the transfer opportunities at them.

  Source: FHWA lists major intermodal connectors, such as airports, rail hubs, and marine ports at www.fhwa.dot.gov/planning/national_highway_system/intermodal connectors.

Social goal objectives

- *Safety* applies to projects that reduce collision or injury rates. State DOTs may include projects from their Highway Safety Improvement Program (HSIP) and other projects that also address mobility. Transit projects may include positive train control and highway–rail grade crossings.
- *Preservation or Rehabilitation* projects address the physical condition of the transportation infrastructure.
- *Quality of Life Enhancement* projects address issues such as providing transportation choices, livable communities, and pedestrian friendly environments.

Project Impact Area: The analyst should identify the breadth of the project's most likely direct economic impact on users, which is generally broader than the location of the project. To make the analysis both useful and practical to complete, this area should be selected as the smaller of: (a) the scale of origins and destinations for affected trips, which may be primarily local or serve broader regional scale or long-distance trips, (b) the area of concern for the parties that are funding the project, and (c) the area for which transportation data and model analysis is available. It should be understood that if "c" is smaller than "a" or "b," then the resulting analysis may underestimate productivity impact.

- *Urban/Metro Area* indicates project within a single metropolitan area, while Rural Area projects may cover a larger, more dispersed area. Many state DOTs distinguish urban and rural projects. The analyst may also use U.S. Census definitions, which distinguish Urbanized Areas (UAs) of 50,000 or more population, from rural and small urban clusters with lesser population base.
  Source: www.census.gov
- *Intercity Connection* refers to a link between multiple urbanized areas (which are defined by the U.S. Census Bureau).
- *Multi-State Region* includes projects that cover long distances. In the case of a large state, such as California, Florida, or Texas, this category may be selected for intrastate projects.
- *National/International Gateway* includes land borders, airports, and maritime ports that provide access to other countries or large parts of the United States.
  Sources:
  Border Gateways: Bureau of Transportation Statistics, Transborder data, www.bts.gov/programs/international/transborder/TBDR_QuickSearch.html
  Marine Ports: U.S. Maritime Administration (MARAD), www.marad.dot.gov/documents/Container_by_US_Customs_Ports.xls
  Airports: Federal Aviation Administration (FAA), www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger

Trip Purpose: The analyst may identify whether the project will serve particular trip purposes because of its location. The trip purposes provided in the checklist generally correspond to those found in travel demand models—freight movement, commuting trips, business travel, and personal/recreation/tourism travel. The analyst may obtain trip purpose information from travel demand models, traveler surveys or local knowledge. Source: If a local travel demand model does not include freight movement, the analyst can then rely on information from truck traffic counts for roads, or freight volume data for intermodal facilities. Tourism and visitor trip data can be harder to obtain, but may be available from discussions with local economic development professionals.

Note that although the above discussion provides detailed information on sources that could be used to answer the checklist quantitatively, the analyst should keep in mind that the checklist is intended to require minimal data (analyst knowledge is fine). More extensive data will be specified and collected in later steps.

Step 1-B: Identify Likely Productivity Impacts

The pre-screening process determines whether productivity analysis is warranted, and whether tools are available to estimate productivity impacts. To accomplish this action, the analyst should take information from the Project Classification Form (Figure 3-1) to identify applicable rows in the Screening Decision Table (Table 3-1). The corresponding columns marked by "X" indicate the applicable outcomes—whether productivity analysis is warranted, and whether tools are available to estimate productivity impacts.

Based on responses to this table, the analyst should match the project to one of the following three situations:

- **Situations where further analysis of productivity impacts is not warranted—**If one or more of the responses from the Project Classification Form corresponds to Screening Decision

Table 3-1. Screening decision table.

Response from Step 1 Project Classification Form	(A) Productivity Analysis is Not Warranted	(B) Productivity Analysis Using Available Tools	(C) Custom Productivity Analysis
Q2 Project Facility Type			
A. Administration or Maintenance Facility	X		
B. Highway/Road (Passenger or Freight)		X	
C. Local Transit (Bus or Rail)		X	
D. Airport, Marine Port, Freight, or Passenger Rail Terminal (Intercity)			X
Q3 Dominant Project Objective			
A. Preservation or Rehabilitation, Safety or Quality of Life Enhancement	X		
B. Congestion/Reliability, Capacity, Travel Time, Metro Market Access, Access to Business Site Location, Intermodal Access		X	
C. Closure/Detour Reduction, Access for Isolated Rural Community, or Service Frequency Improvements			X
Q4 Dominant Project Impact Area			
A. Urban/Metro Area or Rural Area		X	
B. Intercity or Gateway Connection			X
Q5 Trip Purposes Served (Above Average)			
A. Personal Travel (Social, Recreation)	X		
B. Commuting, Business Travel, Freight		X	
C. Visitor Access			X

Table Column A, then the analyst should forego application of the analysis tools discussed because the project is intended to achieve social benefits that are not captured by productivity metrics.

- **Situations where analysis of productivity impacts can be done using available tools**—If all responses from the Project Classification Form correspond to Screening Decision Table Column B, then the analyst will be able to use available tools to estimate productivity impacts.
- **Situations where productivity impacts can be assessed, but other tools are required**—If one or more of the Project Classification responses corresponds to Screening Decision Table Column C, then the analyst will need to plan for at least a portion of the evaluation to build upon analysis tools beyond those identified herein.

3.3 Step 2—Select Applicable Tools

In this step, the analyst applies a Screening Decision Table to determine the types of transportation impact factors that need to be analyzed, and the analysis tools available for measuring them. The Screening Decision Table is used with criteria that include thresholds, so the analyst can determine whether the economic productivity impacts are likely to be large enough to warrant continuing the analysis.

The process for selection of tools under Step 2 has the following two parts:

- Step 2-A: Assess applicability of available transportation analysis tools, and
- Step 2-B: Identify needs for use of custom transportation impact analysis methods. Both are determined on the basis of an Analysis Tool Selection Table that utilizes information derived from the Step 1 Project Classification Form.

The available tools are (a) standard travel benefit calculation systems, (b) reliability analysis tools; (c) market access analysis tools; and (d) intermodal connectivity analysis tools. The tools are summarized in this step and more fully described in Chapter 5.

Step 2-A: Assess Applicability of Available Analysis Tools

First, determine if Step 1 established the project as eligible for productivity analysis using available tools. If so, then the analyst should follow the rest of Step 2-A. If any responses fall into Column C of that table, requiring custom productivity analysis, the analyst should skip to Step 2-B to assess the types of tools that can be used as part of the evaluation.

Second, identify the applicable row in the Analysis Tool Selection Table (Table 3-2), based on the project objective (listed in Column A) and the mode (listed in Column B). The project objective is paired with the mode since applicable tools may vary by mode. Note that both the objective and mode were established in Questions 2 and 3 of the Project Classification Form.

Third, see if the project meets specified threshold requirements, shown in Table 3-2, Column C. The threshold requirements are explained below. Depending on the project type, the threshold test may require additional data collection regarding traffic volume, delay conditions,

Table 3-2. Analysis tool selection table.

(A) Q3 Project Objective	(B) Mode	(C) Threshold Factor*	(D) Analysis Tools**
Travel Time Reduction (Due to Speed, Distance Change)	Road (Car, Truck)	Annual Reduction in VHT > 80,000 hours	STB Analysis (Standard Travel Benefit)
	Public Trans (Bus, Rail)	Annual Reduction in PTT > 80,000 Hours	
Enhance Capacity, Reduce Congestion	Road (Car, Truck)	LOS = D	Reliability Analysis Tool + STB Analysis
	Public Trans (Bus, Rail)	Avg. Volume/Capacity > 0.85	
Travel Time Reliability (Delay Incidence Due to Congestion)	Road (Car, Bus, Truck)	Travel Time Index (TTI) > 1.3	Reliability Analysis Tool + STB Analysis
Metro Area Access between Housing & Employment	Road (Car, Bus, Truck)	Population>50,000 and Density>1800/Sq. Miles	Market Access Tool + STB Analysis
Metro or Regional Business Delivery Access	Road (Freight)	Trucks > 12% of Vehicles	Market Access Tool + STB Analysis
Connectivity to Intermodal Terminal	Road (Freight)	Trucks > 12% of Vehicles	Intermodal Connectivity Tool + STB Analysis
	Road (Passenger)	None	

*VHT = vehicle-hours of travel, PTT = passenger travel time (summed over all passengers); LOS = level of service rating, TTI = travel time index; see Glossary for definitions.

**STB refers to standard traveler benefit analysis, which is addressed in Step 3. The use of reliability analysis tools, market access tools, and intermodal connectivity tools is subsequently discussed in Step 4. Further documentation of these tools appears in Chapter 5.

truck percentage of traffic, or urban area population. If the threshold requirements are not met, it is recommended that the analyst rely on standard travel benefit estimation and not proceed with the added effort required to calculate intermediate drivers of further productivity impact.

If the threshold requirements are met, then the analyst should plan to use the tools for assessing intermediate impact factors that are listed in Table 3-2, Column D. (These tools are described in Step 3.) Note that since multiple responses were allowed for the Project Objective in the Project Classification Form (earlier Figure 3-1), the analyst may need to consult multiple rows of Table 3-2. For example, a project that reduces congestion or increases capacity may also enhance metro area access or intermodal connections. In that case, tools corresponding to those improvements could be used, but the analyst needs to be aware of the potential for double-counting as described in Step 6.

Threshold Requirements. Minimum requirements are recommendations set to save time and resources by limiting analysis to projects that show sizable intermediate impacts that are likely to lead to productivity impacts. The minimum thresholds vary depending on the project type, transportation mode, and setting. Each is explained below. It is notable that roughly similar thresholds have been established for transport project appraisal in the UK.

The travel time savings threshold is defined on the basis of annual VHT time saved, which represents a business cost savings that is roughly in the $1M/year range (depending on the portion of traffic that is either trucks or business-related car travel). It is possible to continue the evaluation of productivity benefits with less time savings, but that is recommended only if there are significant changes in at least one of the other factors—congestion reduction, reliability, market access, or intermodal connectivity.

The congestion threshold is defined on the basis of V/C and LOS.

- Volume/capacity (V/C) refers to the ratio of average traffic volume and road design capacity, where both are measured in terms of vehicles per hour.
- Level of service (LOS) refers to an A-to-F rating system, as defined in the Highway Capacity Manual and AASHTO Green Book. “A” denotes free flow and “F” denotes very slow crawling traffic that is near gridlock. The threshold of D denotes moderately high traffic volumes and slowing conditions approaching unstable flow.

The stated threshold is a V/C ratio greater than 0.85 or a LOS rating at Level D or worse. These thresholds have been set to be consistent with the onset of congestion. Projects on highways with less congestion are unlikely to produce benefits large enough to make the measurement of economic productivity impacts worthwhile. However, the measures and thresholds provided in Table 3-2 are suggestions that can be refined as transportation agencies gain more experience with economic productivity analysis. Note that this approach mirrors the UK guidance that sets minimum conditions for congestion analysis (WebTAG 3.5.7, Annex F), based on a “stress test” that is a form of V/C ratio.

Source: The analyst could use multiple methods from existing STB practices to estimate the V/C ratio for the capacity threshold. For example, the analyst could use state DOT traffic counts, local city traffic counts, or HPMS traffic (AADT) data to calculate a V/C ratio. Alternatively, the analyst could calculate a V/C ratio using methods from the Highway Capacity Manual (HCM) or export a V/C ratio from a travel demand model.

The reliability threshold is defined on the basis of a travel time index (TTI). This measures the ratio of average travel time compared to free-flow travel time on a segment of road. The recommended threshold is a TTI value greater than 1.3. This threshold corresponds to a speed of roughly 45 mph on an urban freeway with a 55 mph speed limit, which is typical for the onset of congestion on such a road. There are other measures for reliability, such as the misery index, buffer time, and standard deviation of travel times. Analysts should select thresholds consistent with agency practices.

Source: For definitions for TTI and other reliability indexes, see reliability analysis tool: Technical Documentation and Users Guide, www.tpics.us/tools/documents/SHRP-C11-Reliability-Tech-Doc-and-User-Guide.pdf. For more information on reliability research from the second Strategic Highway Research Program (SHRP2), see www.trb.org/StrategicHighwayResearchProgram2SHRP2/SHRP2system.aspx.

The metro access threshold represents a minimum for defining urban markets. It is set as population greater than 50,000, which is the U.S. Census minimum for the core of a metropolitan area. Note that this approach roughly mirrors the UK guidance, which sets minimum conditions for agglomeration or market access analysis (WebTAG 8.1.2), though that is based on somewhat higher minimums—a working population over 60,000.

The truck traffic threshold is set to 12 percent based on recent U.S. truck data. According to the HPMS data reported in the FAF, the average truck percentage in the United States is 13.7 percent when weighted by vehicle-miles traveled (VMT). This number will vary considerably by state. For example, the California VMT-weighted average is 11 percent, according to California DOT statistics. The analyst could choose a larger threshold. For instance, in designating a National Freight Network, U.S.DOT has selecting rural freight corridors with at least 25 percent trucks. However, lower thresholds can make sense, particularly for urban freeways that are important truck routes yet also have high volumes of commuter traffic.

Step 2-B: Assess Need for Custom Productivity Impact Analysis

For some classes of projects, there is a current lack of applicable analysis tools. These are classified by the Step 1 Screening Decision Table (Table 3-1) as falling into Column C. For those projects, productivity impacts can still be calculated following the same guidance and sequence of analysis steps provided in this chapter, but additional effort will be required, as explained below.

In general, the problem is that the currently available analysis tools are set up for specific modes, trip purposes, and distance ranges. So while the concepts of reliability and market access are universal across these categories, the currently published range of research analysis has focused largely on urban ground transportation and has yielded a base of economic valuation and response coefficients (and elasticities) for those types of travel. There is less research available at this time on travel by air and marine modes, for recreation, and long-distance (intercity or international) trips. Specific information regarding likely productivity effects and additional research needs are laid out in the Custom Analysis Guidance Table (Table 3-3) and the notes that follow it.

Guidance Notes Regarding Requirements for Customized Analysis

(A) Non-Road: Freight Projects. Air cargo projects may enable just-in-time cargo movements, which could use the market access tool (applied in Step 4) to develop a measure of air cargo market access change. However, further research is needed to establish the applicable $ valuation and elasticities required in Step 5 to calculate changes in productivity elements. It is doubtful that the elasticities now used in that step are applicable for air freight, as that has a higher value/weight composition (and often higher sensitivity to delay) than truck freight. Custom tools are required to establish the productivity benefit of reducing airport delays for air cargo.

Marine and rail freight typically carry a very different mix of commodities than does truck freight, featuring low value/weight ratio and lower sensitivity to delay, so the Step 5 calculation of productivity impacts is even more unlikely to apply for those modes.

Table 3-3. Custom analysis guidance table.

Label	Mode	Facility Type	Objective & Impact Area	Trip Purpose	Guidance
Non-Road: Freight	Air, Marine, Rail	Port, Track, Terminal	Intercity or Multi-State	Freight	Note (A)
Highway Intercity	Road	Highway	Intercity or Multi-State	Freight or Passenger	Note (B)
Non-Road: Intercity (Passenger)	Air, Marine, Intercity Rail	Port/ Terminal	Intercity or Multi-State	Passenger (Business)	Note (C)
Rural Access Road	Road	Highway	Rural Access	Freight or Passenger	Note (D)
Gateway Access	Road, Rail, Air, Marine	Line or Terminal	Gateway	Freight or Passenger	Note (E)
Visitor Access	Any	Any	Any	Passenger	Note (F)
Service Frequency Enhancement	Air, Marine, Rail, Transit	Any	Any	Freight or Passenger	Note (G)

(B) Highway Intercity Projects. A highway project could expand the market area for same-day supply chain delivery and/or same-day business trips, and the Step 4 market access tool could be used to estimate the magnitude of those market access changes for business-to-business access improvement. However, further research is needed to establish the applicable $ valuation and elasticities required in Step 5 to calculate productivity changes for intercity freight or inter-city business travel by highway.

(C) Non-Road: Intercity (Passenger) Projects. The preceding discussion of needs for inter-city highway projects holds for air, marine, and rail intercity passenger movements. Also, the trip purpose mix of passengers (recreation vs. business travel) varies widely between road, rail, air, and marine travelers. As a result, separate $ valuation and elasticity factors are likely needed for those types of projects.

(D) Access Projects for Isolated Rural Communities. The Step 4 access tools also may be used to assess benefits for projects that bring a sufficiently large improvement in travel time to enable previously isolated communities to now fall within the feasible range for workers commuting to more distant urban job locations, and for businesses in isolated areas to now provide same-day business delivery to broader outside markets. However, these rural community access projects often are motivated by the need to serve social needs (access to health care, education, and public services) for isolated communities, and thus may require specialized analysis to establish a more complete productivity impact in Step 5.

Note: Rural access projects may shift the location of business activities in ways that add to GRP for small local areas, but actually represent little gain at a broader regional level. Care must be taken to designate sufficiently large study areas to cover the full area of project impact and thus distinguish net regional productivity gains from localized activity shifts in which one area gains productivity at the expense of another area.

(E) Gateway Projects. These projects serve to facilitate the flow of interstate travel (in the case of air hubs) or cross-border commerce (in the case of international airports, seaports, and border crossings). Access or capacity improvements to these facilities can reduce delay and improve reliability. However, the delays and associated reliability changes occurring for these facilities are typically not associated with the same type of volume/capacity relationships as provided in the Step 4 reliability analysis tool. For that reason, custom analysis is needed, both to estimate how transportation will change reliability in Step 4, and to value and calculate a productivity impact in Step 5.

(F) Visitor Access Projects. Some projects are designed to enhance access for visitors to tourism and convention sites. Those changes can enable a larger number of visitors and increase local visitor spending, and they can lead to local economic growth. However, those changes typically reflect a spatial shift in visitor patterns rather than a productivity enhancement. Exceptions are possible, such as when a project enables "economies of scale" at a recreational attraction or a convention center facility. Such cases are relatively rare, and when they occur, a custom analysis may be necessary to calculate the wider transportation benefits and productivity gain for the facility operator.

(G) Service Frequency Enhancement Project. Some projects can serve to enable more frequent bus, rail, ferry, or air shuttle services. Typically, these involve some improvement in the line capacity (e.g., via added tracks or bus lanes), terminal capacity (e.g., rail platforms, ship berths, or airport gates) or operational improvements (e.g., train control or air traffic control systems). The end result is a reduction in out-of-vehicle wait time and sometimes an improvement for in-vehicle travel time. By adopting transportation impact analysis methods that fully capture both in-vehicle and out-of-vehicle times, it is possible to apply STB analysis methods without the need to invoke broader impact tools for assessing reliability, access, or intermodal connectivity changes.

3.4 Step 3—Measure STBs

In this step, the analyst calculates basic impacts on transportation conditions that are needed to estimate changes in vehicle-miles traveled (VMT), vehicle-hours traveled (VHT), and vehicle collision rates. Those changes are the basis for standard traveler benefit (STB) analysis in the United States, which is more commonly called standard transport economic efficiency (TEE) in the UK. There are further adjustments made in this step to calculate just the travel-related cost savings for business. Some of this same data also will be used for the calculation of wider benefits in Step 4.

The process for measurement of transportation changes under Step 3 has three parts as follows:

- 3-A: Assemble required transportation data,
- 3-B: Calculate STBs, and
- 3-C: Make adjustments to represent business cost savings.

Note that analysts who desire to calculate total productivity gains and economic impacts must complete all three parts of this step. However, some analysts may wish to only calculate the elements of broader impact that are not already captured by their existing benefit-cost or multi-criteria analyses systems. Those analysts may skip Parts 3-B and 3-C, if desired.

Step 3-A: Assemble Required Transportation Data

To proceed further, it is necessary to assemble relevant data pertaining to the study area, transportation facilities, and project changes affecting transportation system conditions. The Table of Data Requirements (Table 3-4) shows the types of data needed for estimating STB impacts and for carrying out additional analysis elements (reliability, market access, intermodal connectivity) that may be required for the full productivity analysis. The notes that follow describe sources of this information. *It is critical to keep in mind that not all of the tools shown in*

Table 3-4. Table of data requirements for productivity analysis.

(A) Data Element (Characteristics of…)	(B) Std. Traveler Benefit	(C) Reliability Analysis	(D) Market Access	(E) Intermodal Connectivity
Volume of activity (e.g., person-trips, vehicle-trips, vehicle mix, avg. vehicle occupancy)	X	X	X	X
Peak period (e.g., percent trips, capacity)	(X)	X		
Facilities (e.g., capacity, service frequency)	(X)	X		X
Network links (e.g., time, cost)	X		X	X
Zones (e.g., population, employment)	(X)		X	X
Labor force (e.g., jobs, wages, occupation)			X	

X denotes required element; (X) denotes element that is required for travel models but optional for sketch planning and engineering estimates.

this table are applicable for any given project. Information from earlier Step 2 (Table 3-2) should be used to identify the specific analysis tools that are applicable for any given project.

Note: The information on data sources that follows is for reference purposes. Before attempting to assemble this information, the analyst should read through the entire set of steps contained in this chapter. That will provide insight into how the data will be used, and whether some of the data is either not needed or already available.

Notes on Data Sources for Table 3-4

Volume (Vehicles and Passengers). FHWA's National Highway Planning Network (NHPN) database provides annual average daily traffic (AADT) counts and truck/car splits for significant highway links at www.fhwa.dot.gov/planning/processes/tools/nhpn. Additional vehicle count data is typically available from state DOTs and MPOs for additional roads, based on Highway Performance Monitoring System (HPMS) data, archived data from automated sensors and travel demand models.

Related information on vehicle-trips, person-trips, and average vehicle occupancy is typically available for public transportation as well as cars and trucks, based on travel surveys and travel demand models provided by state DOTs and MPOs. Average national data is also available from the National Household Travel Survey (NHTS) covering cars and trucks at http://nhts.ornl.gov/tables09/FatCat.aspx?action=excel&id=3, and the U.S.DOT Conditions and Performance Report (CPR) covering bus, rail, and ferry modes, www.fhwa.dot.gov/policy/2010cpr/chap4.htm#10.

Vehicle classification counts (from state DOTs) are often necessary to estimate the volume and share of truck and bus vehicles on roads. In many cases, travel demand models are not useful for estimating truck and bus usage, because freight modeling is often poor and public transportation modeling is frequently done on a mode split rather than a vehicle assignment basis. If necessary, the analyst may use a default percentage, such as the 13.7 percent national average for truck use derived from HPMS data. Bus vehicle shares of traffic vary widely and require local data.

Peak Period. State DOTs and MPOs typically have vehicle counts and/or travel demand surveys that can be used to estimate road vehicle-trips by hour or for the peak period. Capacities by segment can be calculated from travel demand models or from the HCM, http://sjnavarro.files.wordpress.com/2008/08/highway_capacital_manual.pdf.

Facility Characteristics. Information on 3,100 freight intermodal facilities is available from the Intermodal Database of Oak Ridge National Lab, http://cta.ornl.gov/transnet/MOpage.html. Information on passenger intermodal facilities is available from the Bureau of Transportation Statistics, http://www.transtats.bts.gov/IPCD_Facts.pdf. Information on road facilities is available from state DOTs, local cities, transit agencies, and field visits. The U.S. Census Bureau provides road data in its TIGER file dataset www.census.gov/geo/maps-data/data/tiger.html. Some data on aviation and marine facilities is embedded in the Intermodal Connectivity tool described in Chapter 5.

Network Link Characteristics. Link information, such as travel time, speed, and cost, is available from STB analysis. See the Step 3-B discussion.

Zonal Characteristics. Basic information, such as population and employment, is used to calibrate travel demand models. It is also a critical input to the market and intermodal access tools. Population and employment figures can be obtained from state DOTs, MPOs and the U.S. Census Bureau. See Step 4-B discussion.

Labor Force Data. Information about the labor force, such as employment, wages, and occupational statistics are available via the U.S. Census America Fact Finder, an online, searchable tool that simplifies data queries, http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml. Detailed population and employment data for census tracts can also be obtained in convenient forms from private sources: Nielson Claritas Site Reports, http://www.claritas.com/sitereports/Default.jsp and ESRI Business Analyst http://www.esri.com/software/businessanalyst.

Step 3-B: Calculate STBs

Note: The effect on total economic productivity in a given study area can be affected by both (1) travel-related cost savings for directly affected business firms (users of the improved transportation facilities), and (2) broader effects on input costs and output levels for both users and non-users. Part B addresses the former of those two elements. Analysts who have already estimated user benefits through separate processes may skip this part or bring in those results to complete it. Analysts who are only interested in broader impacts that are not already captured by their existing benefit-cost or multi-criteria analysis systems may skip both Parts B and C, if desired.

To complete this part, the analyst must assemble information required for STB analysis, which is identified in Column B of Table 3-4. The data must be assembled and applied in an STB analysis methodology, using either a spreadsheet or an online, Web-based analysis system. The source notes for Table 3-5 define the elements of STB; it is followed by a listing of free STB calculation systems that can be downloaded or accessed from the Internet. Some agencies and consultants have their own custom-built STB calculation systems, which are fine to use.

STBs refer to impacts directly experienced by travelers using the transportation system. (They are sometimes referred to as *user benefits* or *transportation system efficiency benefits*). These impacts include mobility benefits (travel time savings), vehicle operating cost savings (covering fuel consumption and vehicle wear) and safety improvements (including collision-related costs).

Traveler benefits are calculated using projections of the change in transportation conditions (volume, speed, and average delay) that can be generated from travel demand models, traffic simulation models, engineering estimates, or sketch planning techniques. The analyst should report these impacts in terms of annual vehicle-miles of travel (VMT) and vehicle-hours of travel (VHT) and annual collisions.

Changes in transportation conditions are then translated into money impacts, based on coefficients for the value of travel time, vehicle operating cost per mile, and cost of vehicle collisions. Typical values for these coefficients are shown in Table 3-5. Only expenses for business-related travel, which in some cases can include commuting, are considered in productivity impact analysis, so the table shows benefit valuation for only business-related categories of trips. Other benefits associated with personal travel, consumer surplus, and personal benefits of accident reduction do not affect business productivity. See Step 3-C for further discussion of how to isolate business-related travel benefits.

Benefit-cost analysis (BCA) tools may be used to automatically calculate STB results based on projected changes in transportation conditions. These tools can typically separate business and commuting cost impacts from other classes of household cost, personal time, and induced travel effects. Free BCA tools, which already incorporate the Table 3-5 valuation coefficients (or equivalent information), are available on the Web and include

- BCA.net—detailed model for highway projects (Web-based system), www.fhwa.dot.gov/infrastructure/asstmgmt/bcanet.cfm
- CAL-B/C—model for highway and transit projects (downloadable spreadsheet), www.dot.ca.gov/hq/tpp/offices/eab/LCBC_Analysis_Model.html
- MBCA—sketch model for all modes: highway, transit, rail, air, marine (Web based), www.tredis.com/mbca

Table 3-5. Values for STB analysis (business-related travel only).

Benefit or Impact Element	Units for Measuring Change	Type of Conversion	Coefficient (Cost per Unit) *	Source
Value of travel time savings for driver & passengers ($)	Vehicle-hours of travel (VHT)	Unit value of time ($ per vehicle-hour)	CC = $12.00 x 1.1 AVO BC = $22.90 x 1.2 AVO FT = $23.70 x 1.1 AVO	(A)
Value of vehicle operating cost savings ($)	Vehicle-miles of travel (VMT)	Unit value ($ per vehicle-mile or per vehicle-hour)	CC, BC = $0.44 /mile FT = $0.95 /mile or $37.78/hour	(B)
Value of safety savings ($)	Vehicle-miles of travel (VMT), collision rate	Unit value ($ per collision)	$3285/collision (See note for source "C")	(C)

CC = commuting by car, bus, or train; BC= business travel by car, FT=freight truck; AVO = average vehicle occupancy; see Note (A) for value of time for rail, transit, and airline staff. **(A) Value of time savings per vehicle-hour:** This is computed as the value of time savings per person-hour, times the average vehicle occupancy. Source: *U.S.DOT TIGER Grant Program: Benefit-Cost Analysis Resource Guide*, www.dot.gov/sites/dot.dev/files/docs/tiger-12_bca-resourceGuide.pdf Note: The values of worker time for business travel categories (CB and FT) are based on wages paid by employers. For freight, some sources include additional logistics cost factors such as the labor costs for loading dock workers and freight carrying costs. There is a wide range of published values that reach as high as $50 or $60 per hour. See HERS-ST, http://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech05.cfm#sect55 and TTI, http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2008-12.pdf. Savings in commuting travel (valued at roughly half of the wage rate) may be included in productivity measurement when the affected trips are predominantly to/from an employment center where businesses are paying a wage premium to workers in compensation for added travel time delay and expense; See discussion in Step 3-C text. **(B) Cost per mile of vehicle operation:** For cars: American Automobile Association (2012), *Your Driving Costs*, http://newsroom.aaa.com/wp-content/uploads/2012/04/YourDrivingCosts2012.pdf. For trucks, American Transportation Research Institute (2013), *An Analysis of the Operational Costs of Trucking: 2013 Update*, http://www.atri-online.org. **(C) Cost of vehicle collisions on roads:** This value represents the economic cost of collision damage to vehicles for business-related travel. It does not break out costs of medical care which are typically covered by insurance, nor does it count other values associated with pain and suffering and lost wages. Source: *The Economic Cost of Motor Vehicle Crashes*, 2010, www.nhtsa.gov/DOT/NHTSA/Communication%20&%20Consumer%20Information/Articles/Associated%20Files/EconomicImpact2000.pdf.

Step 3-C: Make Adjustments to Represent Business Cost Savings

The analyst should make a series of modifications to STB calculations (Part B) to make them applicable for calculating productivity impacts. This involves some exclusions and additions to more accurately represent the direct cost savings to businesses.

Exclusion of Time and Cost Savings for Personal Travel. Changes in VMT and VHT, and associated values of aggregate travel time and vehicle operating cost savings, must be restricted to just business-related travel. The measure should include impacts associated with: worker travel during work hours ("on-the-clock" travel) and freight delivery. In some cases, commuting travel benefit also may be included. In all cases, benefits for personal and recreational travel should be excluded. While travel time savings for these excluded classes of travel does have a social (willingness-to-pay) value, this value does not affect the cost or output of businesses in the economy. Although households may enjoy vehicle operating cost savings associated with these classes of trips, such cost savings typically lead to shifts in household spending patterns rather than productivity gains for industry.

If the travel benefit analysis is carried out using a travel demand model, then the analyst can usually distinguish impact metrics by mode and trip purpose, and opt to view VMT and VHT measures that only count business automobile and business truck travel. For all other situations, the analyst should calculate a business share of total VHT and VHT based on the truck share of all vehicles, and the business share of automobile travel. The 2009 NHTS indicates that 6.7 percent of automobile trips are for business travel. See www1.eere.energy.gov/vehiclesandfuels/facts/m/2010_fotw616.html.

Addition of Shipper Time and Cost Savings. User benefit calculations for business travel typically count only the time savings for freight carriers and service delivery workers. However, there is growing recognition that in the case of freight shipments, it is the shipper and consignee (receiver) of deliveries who are the true "users" of the freight transportation system, rather than just the freight carrier. For that reason, the estimated business cost associated with travel time delay should ideally be expanded to include excess staff time (and overtime costs) paid to loading dock workers at both ends of freight delivery trips, in addition to the labor cost of driver delay. This can be done through use of the logistics cost analysis framework described in Section 5.5, or by surveying businesses to obtain estimates of the additional loading worker time saved by a proposed project.

Adjustment for Induced Trips. Travel demand models may forecast additional (induced) vehicle-trips following a transportation improvement affecting travel times or distances. As a result, the estimated change in total VHT and VMT may include offsetting effects of both (1) a reduction of travel time or distance per trip and (2) an increase in total trips. To calculate the effect on productivity (cost per business trip), it is necessary to net out the effect of induced trips and just count the VHT and VMT savings for the volume of pre-existing (base case) trips. In other words, the addition of induced trips should not dilute the productivity gain, nor should the "consumer surplus" associated with induced trips add to productivity gain. Note: Additional economic activity enabled by access improvement is addressed separately in Step 4-B. By not counting the impact of induced trips in this step, the analyst avoids double-counting the consequences of access changes that can affect economic growth, and resulting land-use and trip generation patterns.

Optional Inclusion of Commuting-Related Cost. While commuting is commonly treated as a form of personal rather than business-related travel in benefit-cost analysis, there are situations in which a transportation project does enable business cost savings associated with commuting travel. That occurs when the affected trips are predominantly to/from an employment center where businesses are paying a wage premium to attract workers in compensation for the longer travel time, greater delay, or higher expense associated with working there. That applies most typically for travel to large urban centers with congested access and high parking cost, or travel to locations at the fringe of the labor market area (see Appendix A2).

Effect of Reliability Improvement. It has been well established that variability in travel times imposes costs on travelers as they adjust their schedules to allow for potential delay. In the case of freight delivery and service business travel, reliability also has broader long-term impacts on inventory and stocking practices, as well as the deployment and utilization of workers and vehicle fleets. Improvement in travel time reliability reduces those costs and thus improves productivity. However, this impact is not typically included in STB analysis. So while it does provide user benefits, it is addressed as part of the wider benefit calculations covered in Step 4.

3.5 Step 4—Calculate Wider Transportation Benefits

In this step, the analyst uses tools identified in Step 2 and builds upon STB data assembled in Step 3 to estimate the broader transportation effects (beyond direct traveler cost savings) that are drivers of productivity growth. This research recognizes three classes of broader transportation effects—market access, intermodal connectivity, and reliability. These are fundamentally transportation concepts, although they lead to effects on business productivity because they enable longer-term adjustment in business scale and operating processes.

For any given project, the need for reliability, market access, or intermodal connectivity impact analysis tools will have been identified back in Step 2. In most cases, there is a dominant project objective and only one of the three classes of tools will be necessary.

There is one common aspect to use of any of these analysis tools: the need to define input data and collect output measures for both a base case (or "no-build") scenario and a project build scenario. That makes it possible to identify the incremental impact of a project on wider transportation factors, which will then be applied to business impact elasticity factors in Step 5 to generate measures of productivity impact.

The remaining Step 4 text summarizes applicable tools, required data, and the calculation of resulting impacts. It is subdivided into the following three parts:

- 4-A: Use of reliability tools,
- 4-B: Use of market access tools, and
- 4-C: Use of intermodal connectivity tools.

Readers should focus on whichever one of these three parts is most applicable, and ignore other parts of Step 4.

Step 4-A: Use of Reliability Analysis Tools

Applicability of Reliability Tools. There are three different reliability analysis tools described later in Section 5.2. They differ in the level of detail and data requirements regarding road characteristics and conditions. The simplest is the C11-Reliability Tool; the more sophisticated tool is FREEVAL-RL.

All of the reliability analysis tools are designed to analyze project impacts on road travel time reliability. They all build upon the fact that as a road becomes more congested during peak periods, two distinct effects occur—a daily recurring effect in which traffic speeds slow down, and an unpredictable, "non-recurring," effect in which the frequency of traffic incidents and the severity of resulting traffic backups both grow exponentially. This approach applies equally for car, truck, and bus vehicles as long as they share road lanes and do not use separate, mode-specific travel lanes.

In theory, the same general delay and backup measurement concepts also could be applied to other situations—for mode-specific travel corridors, or for rail, air, or marine travel. However, that would require custom analysis to change the network link data to be used and the form of model to be calibrated.

Finally, it should be noted that none of the current reliability analysis tools are of relevance for situations in which reliability is enhanced by projects that make a travel corridor more resilient and less prone to slowdowns, closings, or detours caused by flooding, landslides, rockslides, snow slides, or mud slides. Such projects can enhance productivity, but very local information is required to estimate the incidence of those events.

Input Requirements of Reliability Tools. Basic input and output metrics are summarized in Table 3-6. The reliability tools differ in the level of input information required, although all require some basic information regarding characteristics of traffic volumes and road capacity by time of day, plus information on the terrain (for non-signalized roads) or the green signal ratio of total time (for signalized roads). Sources for traffic volumes were provided earlier in the Table 3-4 notes. Information on facility capacity, terrain, and signalization may be obtained on the basis of direct observation and engineering calculations.

Output Results of Reliability Tools. The reliability analysis tools provide output reports showing several ways of measuring changes in reliability for travel on roads and highways. The analyst should select the aggregate measure of non-recurring delay or schedule padding based on one of the two following impact metrics:

- **Standard deviation of travel time—**This metric represents the variation around the mean travel time (in minutes) that accounts for 68 percent of all cases. It is preferred by academic researchers for its relationship to statistical studies. The standard deviation value represents a two-tailed test that accounts for both early and late arrivals. However, it is also possible to distinguish the early arrival and late arrival aspects of this travel time distribution.
- **Buffer time measure—**This metric represents the amount of time that must be added to average travel times to ensure an on-time arrival 95 percent of the time (representing late delivery no more than once a month). It is preferred by business analysts for its more direct relationship to business scheduling costs. The value represents a one-tailed test that accounts only for late arrival incidence.

Interestingly, these two reliability impact measures are both derived from statistical analysis of variation around the mean, and they tend to yield similar values in many cases, so either one

Table 3-6. Reliability tool metrics.

Type of Tool	Inputs	Outputs
Reliability Analysis Tool	• AADT: Average Annual Daily Traffic (A) • Annual % traffic growth rate (A) • Percent trucks (A) • Peak capacity (A) • Traffic signal ratio and/or terrain type	• Delay: total, recurring, incident delay (vehicle-hours) • Buffer time (vehicle-hours) or standard deviation of delay • TTI

(A) This input data is generally available from STB analysis (Step 3). See Chapter 5 for further details.

can be used as the basis for applying business response elasticities (in Step 5) to calculate direct project impacts on business productivity.

Note: There are tradeoffs involved in the selection of standard deviation or buffer time metrics to represent travel time variability effects. See the discussion of currently available tools in Section 5.2 and the broader discussion of reliability measurement in Appendix A1. See Section 4.2 for an illustration of the computations required to complete this task.

For productivity impact analysis, a further adjustment must be made in the calculation of aggregate trip delay or schedule padding due to travel time variability. The adjustment is to count the impact only for those categories of trips that lead to changes in business operating costs. Savings in average vehicle operating cost and worker time for car business travel and truck freight travel clearly represent direct cost savings for business. However, in some cases it can be important to count business benefits of improvement in commuting trip reliability. That is primarily when evidence is present that employee on-time attendance is a real productivity issue for affected businesses, and the need for some employees to build in significant buffer times (leaving home early to get to work, or leaving work early to get home) raises the need for businesses to provide compensating wage premiums to attract workers. The extent of these situations may differ by industry and location, so the analyst may need to talk with business representatives to assess the extent to which these conditions apply. However, to simply ignore this class of impact is to assume that commuting trip reliability is of no consequence to all employers, and that is likely to be wrong.

Supplementary Analysis: Logistics Impacts. The reliability analysis tools can calculate driver and vehicle costs associated with non-recurring delays and the associated schedule padding, but that calculation will not account for further savings in logistics elements—the added inventory (safety stocks), delivery staff (relief drivers), loading dock workers, physical warehousing capacity, and delivery vehicles that some businesses keep available to allow for unreliability. Further savings in those logistics-related costs are most likely to occur when there is an improvement in reliability on roads that are major truck routes. In such cases, the reliability tools may be used together with the Logistics Cost Analysis Framework. That framework, described in Section 5.5, builds on the fact that there are differences in the value, perishability, and inventory stocking of different types of commodities. As a result, the logistics cost savings from reliability improvements can vary widely depending on the mix of commodities being carried on affected routes.

Note on Data Sources for Commodity Mix. Supporting information on the mix and magnitude of freight flows on a specific road or rail corridor may be obtained from a business survey, estimated with a state or metropolitan freight model, estimated by consultant studies, or obtained from commercial sources such as the TranSearch database of IHS Global Insight, www.ihs.com/products/global-insight/industry-analysis/commerce-transport/database.aspx or the TREDIS Freight tool at www.tredis.com/products/tredis-freight. Some transportation agencies already have this information available. However, others do not and there are costs associated with obtaining freight data from commercial sources.

A rough but free alternative would be to allocate a region's truck movements to industries using the region's mix of business output or employment by industry, adjusted for different trip generation rates among applicable building types. The economic data can be obtained from the U.S. Bureau of Economic Analysis, and used in conjunction with the ITE Trip Generation Manual. The source of error in this approach is that it assumes that all roads in a region have a mix of freight represented by the profile of products manufactured in that region; this does not account for incoming materials to be used for manufacturing or for local consumption. Economic models and the above-referenced freight data sources can correct for (or avoid) this error. However, this approach is arguably better than nothing because it at least enables some identification of areas where high-value products (which are likely to have greater time sensitivity) are represented in the freight mix.

Of course, there is no requirement that logistics cost impacts be estimated, although it should be understood that failure to do so may lead to underestimation of productivity gains, particularly gains that can be realized by shippers of time-sensitive products.

Step 4-B: Use of Market Access Analysis Tools

Applicability of Accessibility Tools. There are two market access analysis tools described in Section 5.3. Both utilize similar core concepts, as follows:

- Subdivision of an urban area or region into a system of zones;
- Calculation of an economic mass or weight metric for each zone, which may be expressed in terms of jobs, workers, population, or another measure of economic activities or opportunities in the zone;
- Use of an impedance (representing travel time or generalized cost) for travel between each pair of zones;
- Use of an importance factor (decay function) that further diminishes the attractiveness of the more distant zones, and/or a threshold factor that eliminates consideration of zones falling beyond a given impedance level; and
- Calculation of market access in terms of the effective mass or effective density of market opportunities surrounding each zone—an effect that can be expressed in aggregate terms as a composite across all zones in the region.

The tools differ primarily in the way that they apply impedance, importance, and threshold factors. Each is optimized to address a different aspect of market access.

In considering the selection and use of these tools, it is important to recognize that various elements of the economy differ in the spatial scales at which they operate and are most productive, and they also differ in the extent to which they gain productivity from localization effects (clustering of businesses with similar or complementary activities) or from urbanization effects (gaining access to a broader labor, supplier or customer markets). The two effects do not always coincide, and no single metric can equally well capture both effects. The selection of a market access tool and the use of employment or population metrics can depend on the scale and nature of the transportation project—for instance, whether it is designed to enhance regional labor force access to a growing employment center, enlarge the local truck delivery areas served from a distribution center, or improve movement between specific business clusters.

NOTE: While there are multiple tools and measurement approaches for calculating market access, and multiple forms of agglomeration benefit, care must be taken to select the appropriate approach to capture relevant productivity impacts and avoid double counting. For more information on options and tradeoffs, see the discussion of currently available tools in Section 5.3 and the broader discussion of agglomeration measurement in Appendix B. See Section 4.2 for an illustration of the computations required to complete this task.

Input Requirements of Market Access Tools. Basic input and output metrics are summarized in Table 3-7. For urban transportation planning, the zones tend to be traffic analysis zones (TAZs), which commonly correspond to census tracts. TAZ-level population and employment data is commonly available from the Census Journey to Work dataset and from the travel demand or GIS models of MPOs and state DOTs. Census tract data may also be obtained from vendors, including Nielson Claritas, at www.claritas.com/sitereports/Default.jsp or ESRI Business Analyst at www.esri.com/software/businessanalyst. A free source is the Census LEHD (Longitudinal Employer-Household Dynamics) dataset and its On the Map tool at http://lehd.ces.census.gov, although that only counts households with active workers employed in private industry. For large-scale projects, analysis zones may be as large as postal zip codes or counties, in which case the Bureau of Labor Statistics' Zip Code Business Patterns and County Business Patterns datasets, or the more detailed IMPLAN dataset, may be used. Some of the tools have practical computational limits on the number of zones that can be analyzed, thus requiring some level of aggregation up from the TAZ zones defined in a model. A further discussion of data sources is provided in the SHRP2 study of market access (Texas A&M University Transportation Institute, 2013).

Interzonal travel times and costs can be directly calculated for those MPOs and state DOTs that have their own travel demand models with road networks. When possible, these values should be converted into generalized costs that combine the value of time and vehicle operating costs. For organizations that do not have their own road network models, the Oak Ridge National Labs (ORNL) Highway Network data may be used to obtain county-level, interzonal impedances (that reflect travel times) for the National Highway System. See http://cta.ornl.gov/transnet/Highways.html. FHWA's Freight Analysis Framework (FAF) provides commodity flows and assignment of commodities to the National Highway System, www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf3/netwkdbflow.

For MPOs and DOTs that do not have network models, it is possible to use commercial Geographic Information Systems that can provide network travel times (between census tracts) for baseline conditions, using the NavTeq or TomTom system used by GPS-based car navigation systems. This includes the ESRI GIS system previously referenced.

Output Results of Market Access Tools. The market access tools provide a measure of either the effective density or effective scale of markets surrounding each zone, as well as an aggregate measure across all zones in a region. Some of them also enable calculation of the monetary value of additional production or output, using a production elasticity. For consistency in following

Table 3-7. Market access tool metrics.

Type of Tool	Inputs	Outputs
Market Access Tool	• Zonal system (A) • Transportation network (interzonal impedance matrix (travel time or generalized cost) (A) • Zonal Activity: employment, population, or business production metric (A) • Distance decay parameter (B) • Maximum threshold impedance (B)	• Effective density from specific zones and for entire region; or • Market Access Index (market size or effective density)

(A) This information may be collected from Census, transportation network models, GIS systems and/or MPO planning datasets. (B) This data can be drawn from built-in defaults and data tables already provided in the tool. See Chapter 5 for further details.

this research, the analyst should calculate an accessibility change index using the ratio of a study area's effective density (or market scale) for the project case, relative to the same value for the base case. An index value of 1.0 means that accessibility has not changed. See Section 4.3 for an illustration of the computations required to complete this task.

Step 4-C: Use of Intermodal Connectivity Analysis Tools

Applicability of the Intermodal Connectivity Tool. One tool is described in Section 5.4; it was developed as part of the SHRP2 research program and can be used to assess the impact of changes in access to (or service at) commercial airports, marine ports, or rail terminals. Data on both freight and passenger intermodal facilities is included with the tool.

Input Requirements of the Intermodal Connectivity Tool. Basic input and output metrics are summarized in Table 3-8. The tool builds upon data regarding both ground access to intermodal terminals and freight and passenger activity levels and destinations served from those terminals. Ground access data—in the form of average travel times from zones to the facility—must be provided by the analyst. This information can come from a road network model or from direct observation of current travel times and engineering estimates of project impact on changes in speed or travel time.

Information on activity levels at the terminals is already entered for commercial facilities in the United States that have scheduled air, marine, or rail service. The data comes from the following sources:

- U.S.DOT's "T-100 Air Carrier Statistics database" and terminal area data files for airports, www.transtats.bts.gov/databaseinfo.asp?DB_ID=111
- The Army Corps of Engineers Waterborne Commerce Statistics data for marine ports, www.iwr.usace.army.mil/About/TechnicalCenters/WCSCWaterborneCommerceStatisticsCenter.aspx
- FHWA's Intermodal Connector Facility List for rail, marine, and air freight terminals, http://www.fhwa.dot.gov/planning/national_highway_system/intermodal_connectors and http://ops.fhwa.dot.gov/FREIGHT/freight_analysis/nhs_intermod_fr_con/app_c_1.htm
- FHWA's FAF for freight flow and terminal destination data, http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

Use of the Intermodal Connectivity Tool. The intermodal access tool provides a means for calculating the time saved by enhanced access to a specific intermodal terminal, weighted by an index of connectivity importance.

Table 3-8. Intermodal connectivity tool metrics.

Type of Tool	Inputs	Outputs
Intermodal Connectivity Tool	For each intermodal terminal • Access to terminal (A) • Surrounding area employment or GDP base (B) • Scale of activity (trips) at terminal (C) • Breadth of connecting services — frequency, destinations served (C)	• Index of intermodal connectivity at the terminal • Importance — weighted cost savings

(A) This input data is generally available from STB analysis (Step 3). (B) This information may be collected from Census, GIS systems, or MPO planning datasets. (C) This data can be drawn from built-in defaults and data tables already provided in the tool. See Chapter 5 for further details.

Output Results of the Intermodal Connectivity Tool. This tool has some conceptual similarity to the market access tools, in that it involves measures of travel time to destinations, and it also estimates the attraction of those destinations. However, it departs from the market access tools because it is specifically designed to reflect travel times to intermodal transfer terminals rather than TAZ, and the broader ways that an intermodal terminal can expand effective market reach by increasing either the frequency of connecting services at a terminal or the number of unique connecting destinations that are directly served at that terminal. As a result, a change in either ground access time to a terminal or in connecting (air, marine, or rail) services available at a terminal can lead to the changes in the connectivity index. That makes the tool useful for assessing the productivity impact of improving intermodal connections.

The current tool is still relatively crude in that the resulting connectivity index does not distinguish between service frequency and destination expansion changes, nor does it distinguish differences in the relative importance of the destinations served. However, it represents a starting point for agencies to address intermodal impacts by enabling them to distinguish the impact of improvements at intermodal facilities and improvements to key travel corridors serving them. See Section 4.4 for an illustration of the computations required to complete this task.

3.6 Step 5—Calculate Productivity Elements

In this step, the analyst calculates the dollar value of impacts on the operational productivity of directly affected businesses. The impacts are in the form of either decreases in business cost per unit of output or increases in output for a given base of labor and capital, which follow as a direct consequence of changes in reliability, market access, or intermodal connectivity. The magnitude of cost or output change is determined by coefficients (drawn from prior research) that represent either the unit value of reliability and connectivity cost savings, plus elasticity factors that represent the percentage change in business output for a given percentage change in market size.

There are two parts in the Step 5 process of translating wider transportation impacts from the prior step (travel, reliability, and accessibility) into business cost or output impacts that ultimately are elements of productivity. They are

- 5-A: Application of coefficients and elasticity factors, and
- 5-B: Correction for overlap and bias.

The research team refers to these values as "elements of productivity" because they are merely first-order impacts on directly affected businesses; they do not reflect broader productivity impacts and total productivity change, which are discussed later in Step 6.

Step 5-A: Translate Wider Transportation Impacts into Business Cost and Output Change

The recommended approach for this step employs a simplified methodology to calculate the change in value added for businesses that are directly affected by changes in travel cost, reliability, market access, and intermodal connectivity—the transportation impacts measured in Steps 3 and 4. This approach calculates three elements of productivity impact as follows:

- Reduction in **transportation costs** incurred by directly affected businesses—including driver, vehicle, and fuel costs (assuming a fixed, current level of business output);
- Reduction in **reliability costs** incurred by directly affected businesses—including costs associated with schedule padding, inventory stocking, and logistics (assuming fixed, current level of business output); and
- Increase in **output** for directly affected businesses—enabled by agglomeration economies associated with enhanced access to labor markets, delivery markets, and/or intermodal connections (assuming a fixed, current set of current labor and capital investments).

All three elements affect productivity—the business output/cost ratio—by either increasing the ratio numerator (output) or decreasing the denominator (cost). The calculation formulas for these elements follow as Equations 1 to 3. Each formula employs coefficient or elasticity values to translate the transportation impacts into productivity (value added) measures. In all of the formulas

Δ refers to change between project case and base case (no-build) values,

%Δ refers to the percentage change between project case and base case values,

Σ refers to the sum for all affected businesses in a defined region.

Equation 1. Gross Value Added due to Change in Business Transportation Costs
(for all business activity that is directly affected by the project)

Δ Σ Business Transportation Cost
= Δ Vehicle operating cost reduction due to Δ VMT or Δ VHT (for all affected trips)
* Business portion of vehicle trips (including product or service delivery trips and business-related worker travel, plus commuting trips when applicable)
* Portion of trip ends occurring in the research area

Note: All data derived in Step 3; coefficients are provided in Table 3-9.

Table 3-9. Typical factors for deriving value (in $) of productivity impact.

Productivity Impact Element	Impact Units	Type of Conversion	Coefficient or Elasticity
Prod. Value of Reliability Time Savings ($)	Buffer Time or Std. Dev. of Travel Time	Unit value per person-hour * vehicle occupancy * reliability ratio	CC: $13.2 ($12.00 * 1.1) CB: $21.98 ($22.9* 1.2 * 0.8) FT: $28.68 ($23.70 * 1.1 * 1.1)
Prod. Value of Market Access Benefit ($)	%Δ Effective Density Index	Productivity elasticity (%Δ Value Added per 1% Δ Effective Density)	Overall 0.05 Manufacturing 0.04 Service industry 0.15
Prod. Value of Intermodal Terminal Access Benefit	%Δ Intermodal Access Index	Productivity elasticity (%Δ Value Added per 1% Δ Intermodal Access)	Airport freight terminal 0.010 Marine port (freight) 0.010 Freight rail terminal 0.005

CC = car commuting, CB = car used for business travel, FT = freight truck used for product delivery.

Equation 2. Gross Value Added due to Change in Business Reliability & Logistics Cost
(for all business directly affected by the project)

Δ Σ Business reliability and logistics cost
= [Δ Σ Vehicle-hours of buffer time (for all business affected trips)
* Coefficient for value of reliability time savings (by trip purpose)]
+ Δ Σ Logistics cost (for added inventory, standby vehicles, and loading/processing staff)

Note: All data derived in Step 4-A; coefficients are provided in Table 3-9.

Equation 3. Gross Value Added due to Agglomeration Effect on Business Output
(for all business directly affected by the project)

Δ Σ Business output due to market access and intermodal connectivity change
= [%Δ Area-wide effective density
* Elasticity for productivity impact of effective density change]
+ [%Δ Intermodal connectivity rating
* Elasticity for productivity impact of intermodal connectivity change]

Note: All data derived in Steps 4-B and 4-C; coefficients are in Table 3-9.

The calculation of Equations 1 to 3 is illustrated in the Chapter 4 case study examples. They rely on coefficient and elasticity formulas shown in Table 3-9. That table provides both coefficients for calculating the productivity effect of reliability change and elasticities for calculating the productivity effect of access and connectivity change. Their values are shown for major mode and trip purpose categories because that is the level of detail at which most MPOs and state DOTs have travel pattern information. For further discussion, see Appendix B.

The **valuation of reliability** is calculated as the Value of Travel Time (from Table 3-5) multiplied by the average vehicle occupancy and reliability valuation ratio. For more information on reliability ratios and valuation, see Chapter 4 of *NCHRP Project 02-24: Literature Review* (Economic Development Research Group et al., 2012) and Cambridge Systematics et al. (2013a,b). Other key research studies include Brownstone and Small (2005); Ghosh (2001); Li, Hensher, and Rose (2010); Borjesson and Eliasson (2008); Small, Winston, and Yan (2005); Carrion and Levinson (2010); De Jong et al. (2009); Fosgerau et al. (2008); Yan (2002); and Asensio and Matas (2008).

The **agglomeration elasticity** of impact on economic growth (productivity effect) is based on a review of past research; see Appendix B3 for a summary discussion. For further information see Chapter 3 of the literature review document (Economic Development Research Group et al., 2012) and Texas A&M Transportation Institute (2013).

- For car travel (commuting and service-related travel), typical values draw from Alstadt et al. (2012) who find a labor market access elasticity for professional services in the range of .04 to

.06 (average .049). Texas A&M Transportation Institute (2013) recommends a slightly higher value of .06 for population market access.
- For truck trips, studies of employment agglomeration elasticities for manufacturing range from a mean of .040 in the Melo et al. (2009) study to a mean of .077 in the Graham (2007) study. Texas A&M Transportation Institute (2013) recommends a value of .03 for manufacturing employment access.
- Studies of the corresponding agglomeration elasticities for business and banking services range from .14 in Melo et al. (2009) to .23 in Graham (2007), but these values reflect a combination of clustering effects and urbanization (breadth of market access) effects.
- Other key research studies include Alstadt et al. (2012); Ciccone (2002); Eddington (2006); Graham et al. (2007, 2009); Melo, Graham, and Noland (2009); Rosenthal and Strange (2003); Venables (2007); and Weisbrod, Vary, and Treyz (2001).

The **intermodal connectivity elasticity** is based on Alstadt et al. (2012). For further information see Chapter 5 of the literature review (Economic Development Research Group et al., 2012) and ICF International (2013).

Step 5-B: Correct for Overlap and Estimation Bias

The wider effects of transportation projects on reliability, market access, and intermodal connectivity are correlated in some cases. They can be correlated with each other and with standard measures of travel time change. For instance, increased road congestion can increase average travel times, and it can decrease the reliability of truck deliveries. The added buffer built into delivery schedules can, in turn, serve to effectively reduce the local customer delivery market for a business beyond the effect of travel time alone, and at the same time it can diminish the measure of local access to airports and rail terminals. For this reason, there can be a perception that these measures are overlapping and will lead to double counting of the productivity benefits of improving traffic flow.

Appendix A provides a discussion and assessment of overlap issues. The general conclusion is that

- A project can change transportation system conditions in ways that lead to multiple forms of impact,
- Those multiple forms of impact can be additive in representing total impact, and
- The fact that these multiple forms of impacts can be correlated (i.e., tend to occur together) is not itself a source of error.

However, the assessment does conclude that the presence of these correlations requires a need for more care in data measurement, analysis processes, and their interpretation. Readers are encouraged to read Appendix A for recommendations on ways to refine their analysis process.

3.7 Step 6—Present and Interpret Productivity Results

This step shows how overall productivity impacts can be calculated, and how the results can be incorporated into one of the three most common methods for evaluating and prioritizing projects: MCA, BCA, or EIA. In addition, the analyst can use economic impact analysis to report changes in macroeconomic productivity, using measures such as labor productivity and multi-factor productivity.

The process at this point depends on which economic presentation or application approaches is to be used. Four alternative approaches are described; only one alternative should be selected, although multiple approaches may be used if desired.

The remaining Step 6 text summarizes applicable tools, required data, and the calculation of resulting impacts. It is subdivided into the following four parts:

- 6-A: Calculation of total productivity impact,
- 6-B: Use of MCA (multi-criteria analysis),
- 6-C: Use of BCA (benefit-cost analysis), and
- 6-D: Use of EIA (economic impact analysis).

Readers may focus on whichever one of these four parts is most applicable and ignore other parts of Step 6.

Step 6-A: Calculate Total Direct Productivity Impact

The most straightforward measure of direct productivity impact is the total annual change in gross value added (GVA) for directly affected businesses. In economic terms, this is the set of businesses that rely on the improved transportation facility for business operations (i.e., worker travel, delivery of input materials, or delivery of products or services to customers). In transportation terms, this is the set of business users that generate incoming or outgoing truck movements and worker travel. The calculation is shown in Equation 4.

Equation 4. Aggregate Change in Gross Value Added
(for all business directly affected by the project)

$\Delta\ \Sigma$ Gross value added
= $\Delta\ \Sigma$ Reduction in business transportation costs
+ $\Delta\ \Sigma$ Reduction in business reliability costs
+ $\Delta\ \Sigma$ Increase in output (revenue) due to market access or intermodal connectivity

Note: All information comes from Step 5 (Equations 1 to 3).

The direct productivity impact can then be calculated as the change in GVA relative to a broader reference metric that measures the affected base of economic activity associated with the same group of affected businesses. The reference comparison may be per worker or per total value added for the base of affected businesses.

The calculation of labor productivity is shown in Equation 5. It is a direct matter of comparing the value added to businesses in the impact area to the base of workers employed in those businesses. However, care is necessary to assure that the area of business impact is carefully defined. Otherwise, there is a danger of overestimation or underestimation of the calculated ratio.

Equation 5. Aggregate Change in Gross Value Added per Worker
(for all business directly affected by the project)

Δ Σ Gross value added per worker
= ΔΣ Gross value added (from Equation 4)
/ Σ Employment

Note: GVA measure comes from preceding Equation 4 in Step 6. The affected employment base can be derived by measuring the quantity of affected business-related car and truck trips (per day, month, or year) and the associated ratio of zonal employment/trip. The zonal employment data is normally available from travel demand models or other datasets required for Step 3 analysis of transportation impacts.

If the analyst is confident that the business impact area has been appropriately defined, then it is possible to calculate a rough approximation of the ratio of the change in GVA per wage dollar as shown in Equation 6.

Equation 6. Ratio of Change in Gross Value Added per Wage Dollar
(for all business directly affected by the project)

Δ % Σ Gross value added
= ΔΣ Gross value added (from Equation 4)
/ [(Σ Employment) * (avg. compensation per employee)]

Note: See Equation 5 note for GVA and employment sources; employee compensation per worker may be obtained from Zip Code Business Patterns, www.census.gov/econ/cbp.

It is important to note that these various metrics will have radically different scales. For instance, the total change in GVA can look substantial, while the per worker ratio will be modest, and the per wage dollar change will appear very small. The case study examples illustrated in Chapter 4 indicate the productivity impact ranges for major projects; more typical projects that appear in a region's transportation improvement plan (TIP) may be one tenth of those sizes. This leads to the following likely ranges of annual impacts for highway and transit projects:

- Change in GVA (annual)—Large projects may cause increases in the millions of dollars; small projects may cause increases in the thousands of dollars per year;
- Change in GVA per worker (annual)—Large projects may be in the hundreds of dollars per worker; small projects may be a few dollars per worker per year;
- Change in GVA per wage dollar (annual)—Large projects will have increases in units of a few tenths of 1 percent of the wage base; small projects will be in units of hundredths of a 1 percent.

To calculate the above ratios, it is necessary to obtain pre-project or baseline estimates of the associated level of employment (and, if desired, worker compensation) associated with the affected base of business activities. Generally, it is possible to obtain information on employment, payroll, and/or value added for a state, metropolitan area, county, city, or zip code from the U.S. Census at www.census.gov/econ/cbp. For organizations that have the REMI or TREDIS economic impact models, this information has already been estimated or calculated for the applicable study area and can be extracted from those systems.

Calculation of Multi-Factor Productivity (MFP). Multi-factor productivity (also known outside the United States as *total factor productivity*) is based on the calculation of a project's value added impact relative to total GVA or GDP—which reflects business expenditures on labor, capital, and capital services. MFP is the most comprehensive form of productivity measurement, as it reflects the mix of inputs that firms use to produce output, and the associated prices of those inputs. Changes in MFP can occur due to the direct impacts of a project on affected firms, as well as further changes that are triggered in business investment, costs and prices of labor, goods, and services.

If the analyst wants to calculate change in total multi-factor productivity, then it is necessary to use a regional economic impact simulation model that incorporates spatial patterns of economic activity with sensitivity to changes in labor, supply chain, and transportation-related costs, as well as investment and trade patterns, to portray productivity impacts.

Step 6-B: Utilize Productivity Impact in Multi-Criteria Analysis (MCA)

Many transportation agencies are not actually interested in measuring total productivity, but rather desire to consider the potential productivity impacts of projects in their decision making. Many use MCA rating systems that allow for various project rating criteria to be used, depending on whatever the decisionmakers feel is of interest for either strategic growth or broader public welfare purposes. The literature review showed how various state DOTs currently have MCA systems that incorporate transportation cost, reliability, market access, and intermodal connectivity metrics. Many of those measures are variants of the intermediate transportation factors developed in Step 4.

The recommended approach for transportation agencies that rely on MCA for project prioritization is to adopt metrics from one of the following three categories:

Wider transportation impact factors developed in Step 4,

Direct productivity elements developed in Step 5, or

Total productivity measures developed in Step 6-A.

These categories represent different perspectives for viewing and measuring the same general effects. For that reason, sometimes it may be appropriate to select multiple criteria *within* any one of these categories, but care should be taken to avoid overlap if metrics are selected that span *across* multiple categories. The recommended options for selection of MCA measures are shown in Table 3-10.

It should be noted that the business transportation cost savings is likely to capture the same impacts as other MCA criteria pertaining to overall travel time or speed improvement.

Table 3-10. Portrayal of productivity effects in multi-criteria rating of projects.

Factor Driving Productivity Impacts	Recommended MCA Indicators
Business Travel Cost	• Value of Business Transportation Cost Savings (A)
Reliability	• Reliability Measure: Avg. Buffer Time or Std. Deviation of Time (A) • Value of Reliability Cost Savings (B)
Market Access	• Change in Effective Size of Effective Density (A) • Value of Market Agglomeration Benefit: Growth Effect (B)
Intermodal Connectivity	• Intermodal Connectivity Index (Activity-Weighted Cost Savings) (A) • Value of Intermodal Connectivity Benefit: Growth Effect (B)
Total	• Change in GVA (C) • Change in GVA per Worker (C) • Change in GVA per Payroll (C)

(A) STB and intermediate transportation factors from Steps 3-4; (B) Direct productivity element from Step 5; (C) Total productivity measure from Step 6-A.

Additionally, if the reliability, access, and connectivity effects are small, then the total productivity impact metrics may end up highly correlated with the measures of travel time and vehicle operating cost savings.

Step 6-C: Utilize Productivity Impact in Benefit-Cost Analysis (BCA)

The results of Step 5 can be incorporated into benefit-cost analysis. In this enhanced form of BCA, the frame of reference must be adjusted so that freight users are defined as the shippers and consignees who pay for the freight transportation service, rather than truck drivers or freight carriers. This shift in frame of reference is consistent with recommendations in various reports from the U.S.DOT Freight Office and NCFRP. It is also consistent with the treatment of public transportation, in which costs and time savings are counted for the passengers (who pay for the service) rather than the bus drivers or carriers (who own the vehicles).

The enhanced BCA also needs to include travel time reliability benefits, which are not part of the standard BCA procedures. There is a strong theoretical case building in the literature for including travel time reliability in BCA. In addition, it is one of the three drivers (along with market access and intermodal access) identified in these steps. Including travel time reliability benefits with STB improves the precision of measuring user benefits. For an expanded BCA, the analyst can simply add reliability benefits estimated in Step 5 as additional user benefits.

Furthermore, an enhanced BCA can include benefits associated with market access and intermodal connectivity as externality benefits that occur due to economies of scale in some business operations. These benefits are beyond the valuation of travel time savings because that leads to the reorganization of business operations (including logistics processes) to achieve greater economies in production, inventory, or delivery processes.

Taken together, these changes enable the analyst to incorporate the results of Step 5 into BCA by reporting STBs and travel time reliability as parts of total user benefits, and then adding externality benefits from market access and intermodal connectivity changes as part of total social benefits.

Classifying Internal and External Benefits

Technology adoption effects enabled by reliability improvements may be classified as externalities, insofar as they affect parties beyond the traveler using the transportation system. However, if the class of all freight shippers and consignees (receivers) is defined as the true users of the freight transportation system, then these impacts may alternatively be classified as internal economies associated with business reorganizations that may occur after a time lag.

Agglomeration and market access effects are technically classified as external economies of scale because they affect otherwise uninvolved residents and businesses in a region (who are not themselves users of the transportation system) by enabling product innovations and effects on the quality and price of products.

Step 6-D: Utilize Productivity Impact in Economic Impact Analysis (EIA)

The Step 5 results may be input into a regional economic simulation and impact forecasting model to generate more complete estimates of shifts in regional income generation, output growth, exports and investment, as well as further productivity changes that result from saving cost and/or expanding markets for directly affected businesses.

Dynamic multi-regional economic models (e.g., REMI TranSight, INFORUM, TREDIS, and various CGE [computable general equilibrium models]) may be used to forecast the impacts of cost changes on flows of labor, investment, and trade. Static input-output models (e.g., IMPLAN, RIMS-II, and R/ECON) cannot be used because they lack that capability. Land-use transportation interaction (LUTI) models—at least in the form currently available in the United States—are not applicable because they estimate business activity location changes only within a region, given a fixed forecast of regional growth and trade with the outside world.

To include productivity impacts in an economic impact analysis, the analyst may use the results of Steps 3, 4, or 5 as input into a macroeconomic impact model. Although Table 3-11 lists these potential inputs, the feasible set of actual inputs will depend on the specific model. One of the classic problems with CGE models has been their limited set of inputs. Traditionally, CGE models have been very sensitive to freight costs, but have had limited sensitivity to commuting and business passenger costs. The REMI TranSight and TREDIS models, in varying and differing ways, both respond by including an economic geography element that provides some

Table 3-11. Potential inputs for macroeconomic models.

Impact Element	Input Metric for Economic Impact Model
Travel time + vehicle operating cost savings (traditional user benefit; optional to add safety)	Business operating $ cost savings
Improved reliability: freight and service delivery	Business $ cost savings (via logistics cost)
Improved reliability: worker commute trips	Business $ cost savings (via labor cost)
Expanded Access: Freight and Service Delivery	Business output/cost (delivery scale economies)
Expanded access: labor (commute) market	Business output/cost (labor scale economies)
Intermodal connectivity: freight delivery	Business $ cost savings (via logistics cost)
Intermodal connectivity: business travel	Business $ cost savings (via labor cost)

sensitivity to changes in commuting and business travel times and costs, as well as freight travel times and costs.

After the analyst inputs these metrics into the macroeconomic impact model, various output metrics may be generated. Standard measures to report include changes in Gross Domestic Product (GDP) or Gross Regional Product (GRP), personal income, and employment. These results can have further use if a multi-regional model form is used, since that can show how effects on changes in the spatial pattern of business access lead to shifts in the relative economic growth of regions. Sometimes, these latter impacts can be significant even if overall productivity changes are modest.

CHAPTER 4

Case Studies: Calculation Examples

This chapter presents three illustrative cases designed to show how the steps presented in the prior chapter can be applied in real world situations. The cases cover different modes (highway and rail); types of projects (a bypass, route capacity expansion, and terminal access route); passenger and freight travel, and both high-density urban and low-density locations. In addition, each case discusses how the steps can be used with travel demand models, when available, and via engineering and sketch planning methods when travel demand models are not available.

Since each case is long and demonstrates all six steps, there is no need to read through all three cases. The main difference among the cases is that each one utilizes a different one of the three types of wider benefit analysis tool: reliability, market access, and intermodal connectivity. For that reason, readers are encouraged to first read Section 4.1 on the overall design of the cases and how to best learn from them, and then read whichever one of the three detailed cases appears most directly applicable to their particular situations. Additionally, a summary of lessons learned is provided at the end of each case, to aid readers who may not wish to view all details of the case calculations.

4.1 Overview, Use, and Interpretation of Case Studies

There are three illustrative cases.

Example A. A bypass road developed to avoid a congested stretch of urban highway (with analysis that includes use of a reliability analysis tool);

Example B. Highway and/or transit improvements for a suburb to central business district (CBD) access corridor (with analysis that includes use of a market access tool); and

Example C. Improvement to an airport connector route for air cargo travel (with analysis that includes use of an intermodal connectivity tool).

To ensure realism, the case studies draw from traffic data for the Salt Lake City region, and use the travel demand modeling system of the Wasatch Front Regional Council (WFRC). However, although the case studies did draw upon data for actual roads, the case studies themselves and travel impacts attributed to them are entirely fictitious and have been transferred to generic maps that do not reflect the Salt Lake City area. As hypothetical projects, they are merely intended to illustrate the types of projects that are typically considered by MPOs and state DOTs.

Although the WFRC model is based on CUBE Voyager software, any similar standard travel demand model system, or a more simplified sketch planning process, could be used to develop inputs for the STB analysis. Where relevant, certain inputs used to calculate project benefits and impacts were calculated without use of a travel or economic model to show how results can be calculated (with different results) via more simplified sketch planning processes.

These examples are not exhaustive, but are meant to illustrate the range of possible applications for productivity impact calculations. Whenever dollars are saved—regardless of how they are saved or where the business is located, whenever markets are expanded—regardless of the mode of transportation used to access the expanded market, and whenever people or goods are more reliably available—regardless of where they arrive or by what mode, businesses may respond to those changes in ways that improve productivity.

The economic factors driving the productivity gain (in business terms) are basically similar across all contextual factors. For example, the fundamental performance elements driving business productivity are not necessarily any different when the performance is improved by a transit investment or a highway investment, or if the affected businesses happen to be in urban or rural areas, or if the dollars are saved from freight deliveries or workforce commuting.

For this reason, the combination of modal, urban-rural, and freight-passenger combinations addressed in case studies illustrating these methods and tools can be practically infinite. The case examples were selected without any intention of demonstrating every possible combination. Instead, they are intended to clearly convey the underlying drivers of productivity gain, and how it can be assessed, with the understanding that the methods demonstrated can be transferred to different modal, geographic, and transportation market contexts.

4.2 Example A—Bypass Route to Enhance Reliability

Summary of Key Inputs and Characteristics. This case assesses two categories of impacts associated with construction of a new bypass route: (1) reductions in overall travel time and cost and (2) enhanced reliability for business travel and truck deliveries, from a reduction in the amount of non-recurring (incident-related) delay experienced by travelers. Key data inputs are

(1) STB	(2) Wider Benefit from Reliability	Both (1) and (2)
Change in VMT and VHT, by trip purpose	AADT, peak capacity, # of lanes, traffic growth rate, and % trucks	Cost factors, by trip purpose

In this example, there is a proposal to construct a four-lane CBD bypass highway that will enable longer distance crosstown traffic to avoid a highly congested bottleneck in the central region (see dotted line in Figure 4-1).

This proposed project can result in faster speeds (less recurring travel time delay) and better reliability (less non-recurring delays resulting from fewer incidents and shorter traffic backups). Since the bypass route also diverts some traffic from the congested route, it provides these speed and reliability benefits to both users of the bypass route and others who remain on the existing highway.

This project can affect productivity in three ways. First, the speed improvement can reduce average delivery vehicle costs for crosstown trips. Second, it can enhance reliability for business

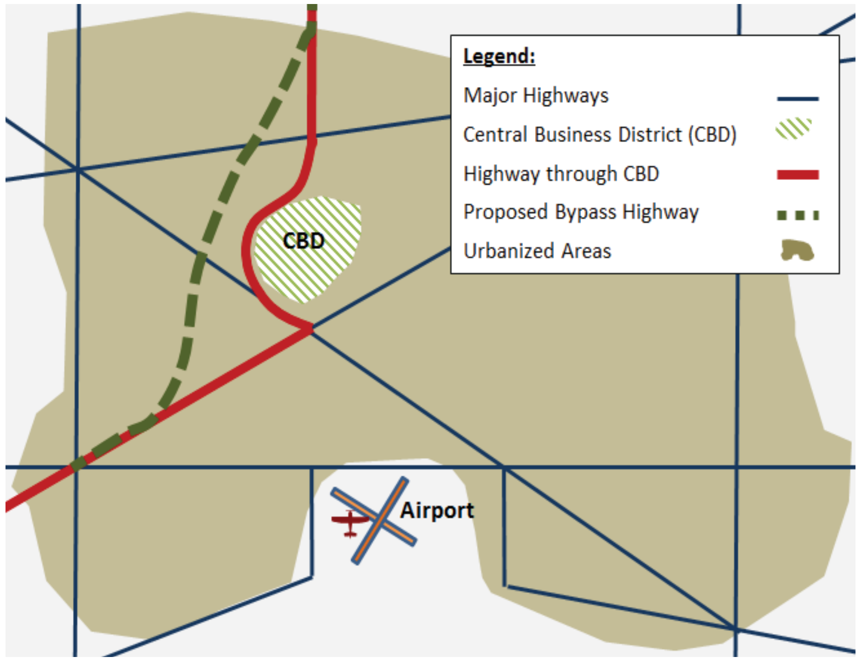


Figure 4-1. Bypass highway route.

travel and truck deliveries across the city, enabling a reduction in logistics and inventory costs. These two productivity impacts occur in the form of businesses saving transportation costs.

The third effect occurs to the extent that a project enhances the reliability of employee arrival at work. It occurs most notably when a project reduces bottleneck or congestion delays on a major commuter route to a business center or cluster. In that case, productivity can be enhanced by enabling either greater workplace output or less employer cost—depending on the degree of reliability enhancement and the extent of business employee reliance on the affected access route. Since this third class of impact may be applicable for some, but not all situations, the case study shows productivity calculation results with and without counting the benefits for commuting trips.

Step 1: Bypass—Initial Screening for Productivity Impacts

In Step 1, the analyst develops a profile of the project under consideration and determines whether productivity analysis can, and should, be conducted. The project is classified using the Project Classification Form (from Figure 3-1).

Project Classification Form

1. Project Name:	*Highway Corridor Improvement*
2. Project Facility Type:	*Highway/Road*
3. Project Objective:	*Congestion/Reliability, Capacity/Future Growth*
4. Project Impact Area:	*Urban/Metro Area*
5. Trip Purpose:	*Commuting, Business Travel, Freight Movement*

Based on the above classifications, the project is assessed using the Screening Decision Table, which indicates that the project can undergo a productivity analysis using available tools.

Step 2: Bypass—Selection of Applicable Tools

In this step, the Analysis Tool Selection Table (Table 3-2) is used to determine the types of transportation impact factors that can be analyzed, and the analysis tools available for measuring them. Based on the project objectives, both an STB analysis and an assessment with the reliability impact tool are warranted. The project passes the associated threshold factors for both of those analysis tools.

- **Capacity.** The threshold for projects aimed at congestion or capacity is a volume-to-capacity ratio greater than 0.85 or a level of service worse than D. The current volume-to-capacity ratio on the existing highway being analyzed is as high as 0.95 on certain portions of the corridor. The V/C ratio was extracted directly from a travel demand model. If a model were unavailable, the analysis could have relied upon AADT values published by the state DOT and engineering calculations of highway capacity.
- **Reliability.** For a project aimed at reliability (delay incidence) for passenger and freight road traffic, the threshold is a travel time index (TTI) > 1.3. A TTI of 1.3 corresponds to the onset of congestion for a freeway (the 1.3 value means that average travel times are 30 percent higher than free-flow travel times), a condition that is met for the highly congested highway (V/C=0.95 in places).

Step 3: Bypass—Measurement of Transportation Changes

In Step 3, the basic impacts of the project on transportation conditions are calculated as inputs to an STB analysis.

Travel characteristics in the base and build cases are summarized in Table 4-1, as obtained from a travel demand model. Trips on the corridor increase slightly because travelers can switch from more circuitous routes elsewhere in the network to the improved corridor. Overall, VMT goes down for two reasons:

- For some users, the bypass is more convenient, resulting in shorter trips, and
- Relieved congestion enables some travelers to switch away from more circuitous routes elsewhere in the network to the improved corridor.

The bypass also enables considerable time savings on the combined corridor.

Adjustment for Induced Trips. To calculate the effect on productivity (cost per business trip), it is necessary to net out the effect of induced trips and just count the VHT and VMT savings for the volume of pre-existing (base case) trips. In other words, the addition of induced trips should not dilute the productivity gain, nor should the consumer surplus associated with induced trips add to productivity gain. Table 4-2 presents a summary of travel characteristics after netting out the effect of induced trips. Note that if the travel characteristics had been developed using engineering estimates that did not predict induced trip making, this step would not

Table 4-1. Bypass: Travel characteristics (daily, with induced trips).

Scenario	Vehicle-Trips	VMT	VHT
Base	85,699	572,399	18,959
Build	88,270	549,855	14,696
Build - Base	2,571	-22,544	-4,263

Note: The above numbers include personal and commuting trips that are included in the subsequent productivity analysis for this route.

Table 4-2. Bypass: Travel characteristics (daily, without induced trips).

Scenario	Vehicle-Trips	VMT	VHT
Base	85,699	572,399	18,959
Build	85,699	533,840	14,268
Build - Base	0	-38,559	-4,691

Note: The above numbers include personal trips that will not be included in the subsequent productivity analysis.

be required. (Nevertheless, understanding induced demand is important for accurately predicting congestion levels in the build case.)

Adjustment to Represent Business Costs. In this case, productivity effects of VMT and VHT savings accrue to long-distance car business travel and truck freight travel that is not destined for the CBD. Personal trips are excluded for the purpose of a productivity analysis. Commuting trips can be counted in some cases, particularly when the transportation improvement reduces the cost of commuting to a business cluster with high transportation costs for workers. However, that condition does not hold in this case. Nevertheless, results are presented with, and without, the benefits accruing to commuters, as these benefits are applicable in other situations.

The annual impact in terms of vehicle-miles traveled (VMT) and vehicle-hours traveled (VHT) is presented in Table 4-3 for passenger car commuters, business travelers, and truck freight. The travel demand model breaks out travel information for car commuting and truck freight, but not for business travel. Therefore, based on 2009 NHTS estimates, it is assumed that 6.3 percent of total car trips are for business.

The valuation of these VMT and VHT changes is based on unit valuations shown in Table 3-5. The results are presented in Table 4-4.

Step 4: Bypass—Calculation of Wider Transportation Factors

Based on tool selection in Step 2, the corridor's effects on congestion and reliability are assessed using the reliability analysis tool. The following inputs in Table 4-5 were used in the analysis.

Current AADT for the existing highway is drawn from the state DOT's traffic statistics website (based on traffic counts). The percent of trucks is drawn from the same source. All other input information is based on project descriptions from the managing agency.

Values from Table 3-5 were used in place of the tool's default values for the value per vehicle-hour of personal and commercial travel time, to be consistent with the valuation of travel time

Table 4-3. Bypass: Change in VMT and VHT, from base (annual, in thousands).

Mode and Purpose	Change in VMT (Build-Base)	Change in VHT (Build-Base)
Passenger Car Business	-596.86	-72.62
Passenger Car Commute	-2,005.06	-243.96
Truck Freight	-551.39	-67.09

Table 4-4. Bypass: Value of annual VMT and VHT savings (without a model, in millions of dollars).

With Model	Annual Savings ($ Millions)	
Mode and Purpose	VMT Savings Value	VHT Savings Value
Passenger Car, Business	0.26	2.00
Passenger Car, Commute	0.88	2.93
Truck Freight	0.52	1.75
Total with Commuting	1.67	6.67
Total without Commuting	0.79	3.75
	Annual Total Savings ($ Millions)	
With Commuting	8.34	
Without Commuting	4.53	

in Step 3, above. Note that the value of travel time used for car trips corresponds to the business value of time, rather than the personal value of time, as it is business cost savings that are counted in a productivity assessment. A post-processing adjustment to the savings calculated will be applied to count only the 6.3 percent of total car trips that are assumed to be made for business. No incident management strategy is included in the project under assessment and therefore the reduction in incident frequency and duration was assumed to be zero. Default Reliability Ratio values (embedded within the tool) were also used. The reliability ratio is defined as the ratio of the value of reliability to the value of travel time. For personal trips, the default value is 0.8, and for commercial trips it is 1.1. Table 4-6 presents the inputs to the tool that capture the capacity increase between the base and build cases. Note that all inputs to the reliability tool are relatively simple and can be developed with and without a travel demand model.

Table 4-5. Bypass: Reliability analysis tool inputs.

Input	Value
Time Horizon	15 years
Analysis Period	6:00 AM to 7:00 PM
Highway Type	Freeway
Begin/End Mile Point	1/12
Free-Flow Speed	65 mph
Current AADT	77,000
Estimated Annual Traffic Growth Rate	2.733%
Percent Trucks in Traffic	5%
Terrain	Flat
Business Travel Time Cost (per veh-hour)	$22.90 x 1.2 AVO = $27.48
Commercial Travel Time Cost (per veh-hour)	$23.70 x 1.1 AVO = $26.07

Table 4-6. Bypass: Capacity and growth rate inputs.

Without a Model: Inputs to the Reliability Tool	Base (No Build)	Build (No Model)
Number of Lanes (each way)	2	3
Peak Capacity per Hour (pcph)	4,400	6,300

Step 5: Bypass—Calculation of Direct Productivity Elements

Travel Time Variability. The reliability analysis tool calculates congestion metrics and congestion costs in a future year for each of the scenarios. Table 4-7 presents summary congestion metrics for the entire day. These condensed results are based on hourly calculations performed by the tool for each hour of the day, and thus account for the higher reliability costs that accrue during peak periods. The "details" view of the tool can be used to view these hourly calculations.

Cost of Travel Time Variability. The reliability analysis tool also estimates costs of both recurring and non-recurring delay. The cost of non-recurring delay is referred to as the cost of unreliability. Recurring delay costs correspond to congestion delays traditionally estimated using STB analysis and thus should be removed if an STB analysis is being conducted, so as not to double count. The cost of unreliability is calculated using unit travel time costs and the personal and commercial reliability ratios (the ratio of value of travel time reliability over value of travel time). Unreliable travel times cause travelers to make early departures to "buffer" against potential delay. The cost of unreliability accounts for this effect and represents the monetized cost of the difference between a worse-than-average and an average trip. Table 4-8 shows the annual weekday costs of unreliability for base and build cases. Only 6.3 percent of the calculated passenger unreliability costs are counted as costs borne by firms in the region, based on the assumption that 6.3 percent of total car trips are made for business.

The tool indicates a savings of $1.29M in reliability-related costs for both business and commercial travel, due to reduced congestion. (That is calculated as the difference between $1.34M in the base case and $0.41M in the build case).

Effects on Productivity Elements. While productivity is defined as the ratio of { business output/business operating cost }, the reliability impact calculations show incremental changes only in the denominator of that ratio. Results are summarized in Table 4-9. They show that the

Table 4-7. Bypass: Reliability analysis tool results (single weekday).

Congestion Metrics Future Year — 2028	Base (No Build)	Build
Overall Mean TTI *	1.48	1.05
TTI_{95}	2.23	1.17
TTI_{80}	1.73	1.06
Trips Less than 45 mph	38.53%	6.82%
Trips Less than 30 mph	17.83%	0.88%

*TTI = travel time index, which measures the ratio of average travel time to free-flow travel time on a segment of road. TTI_{95} and TTI_{80} are the TTI for trips in the 95th and 80th percentiles of travel.

Table 4-8. Bypass: Annual cost of unreliability (in future year, 2028).

Reliability Analysis Results (Annual)	Base (No Build)	Build
Passenger Cost	$9,878,928	$286,395
Business Cost (= 6.3% of Passenger Cost)	$622,372	$18,043
Commercial (Truck) Cost	$713,533	$22,964
Total Cost of Unreliability for Firms	$1,335,906	$41,007

addition of reliability costs adds nearly 30 percent to the cost savings for commercial trip purposes (business trips and commercial truck trips).

Step 6: Bypass—Overall Productivity Results

The only factors affecting productivity in this case are savings in transportation costs due to speed and reliability effects. There are no changes in business output from broadened market reach. That makes the calculation straightforward, as shown in Table 4-10.

Key Findings from the Reliability Case Study

1. This case study illustrated how productivity calculations are to be carried out for a situation in which the major project impact is to reduce congestion and enhance travel time reliability.
2. The inclusion of reliability benefits added nearly 30 percent to what was otherwise calculated as the travel time savings counted in STB.
3. Altogether, the selected case study showed very modest productivity gains—the effect for commercial trip purposes was $158 per worker annually.
4. The potential productivity gain associated with commercial vehicles was relatively low because the selected case study example was an urban arterial corridor that was not a major truck route.
5. The calculation of productivity impact could be very different—and make a far larger impact on productivity—if it involved a truck route corridor that had high levels of truck vehicle movement.
6. Other factors affecting the magnitude of productivity impacts include the initial level of congestion (volume-to-capacity ratio), and the annual growth rate of traffic.

Table 4-9. Bypass: Effects on productivity elements (in millions of dollars/year).

Productivity Factor for Affected Business Firms	Savings
Change in Annual Business Output (Value Added)	No Change
Change in Annual Business Operating Cost Due to VMT and VHT Reduction (from Step 3) Due to Reliability Improvement (from Step 5)	Savings of $5.8 $4.5 $1.3

Note: Annual business operating cost does not include savings for commute trips. Reliability improvements savings are counted for business and commercial truck trips only.

Table 4-10. Bypass: Calculation of overall productivity results.

	Concept	Source	Corridor Impact
	STUDY AREA METRICS		
1	Employment Base	Given	28,500
2	Annual Wage Income	Given	$2.29 Billion
3	GDP or GRP (Representing GVA)	Given	$6.8 Billion
4	Trip Ends Within the Study Area	Travel Model	77%
	Project Impact		
5	Change in Value Added from Revenue Growth	Note 1	0
6	Change in Value Added from Cost Reduction	Note 2	$4.5 Million
7	Total Change in Value Added	= Rows 5 + 6	$4.5 Million
8	% Change in Value Added from Rev. Growth	= Rows 5 / 3	0
9	% Change in Value Added from Cost Reduction	= Row 6 / 3	+ 0.07%
10	Total % Change in Value Added	= Row 7 / 3	+ 0.07%
11	Change in Value Added per Worker	= Rows 7 / 1	$158
12	Change in Value Added per Wage Dollar	= Rows 7 / 2	.002

Note 1. This value comes directly from the effect of increasing the effective density of the regional market, which is not relevant in this case.
Note 2. This value comes from the change in business operating cost due to time savings and reliability enhancement, as calculated in Steps 3 and 4 (also shown in Step 5), multiplied by the fraction of trip ends that are within the study area, from Line 4.

4.3 Example B—Multimodal Corridor: Market Access

Summary of Key Inputs and Characteristics. This case assesses two categories of impacts associated with a coordinated set of road and transit projects that improves access between outer and inner areas of a metro area: (1) reductions in overall travel time and cost and (2) broadened market access to outlying areas that brings agglomeration economies associated with a wider business delivery market. Key data inputs are as follows:

(1) STB	(2) Wider Benefit from Reliability
Change in VMT, VHT, and cost factors, by mode and trip purpose	Zonal employment and GDP, changes in zone-to-zone travel time/impedance

In this example, access to a business district from the northwest and southeast is currently limited by slow road and transit conditions. The proposed project is a coordinated set of road and transit enhancements that improve travel times on the corridor.

This affects overall regional accessibility, although the access improvement is most pronounced for access to the central region (B in Figure 4-2) from outlying fringe or satellite city areas (A and C in Figure 4-2, with the effect being stronger for area C).

This project can affect productivity in two ways. First, it can provide labor cost and delivery vehicle cost savings for movements between the business district and selected outlying areas. Second, it can effectively broaden market access to outlying areas—represented in terms of increasing effective density—enabling agglomeration economies associated with both business delivery markets and labor market access to specialized workforce skills. This example focuses on assessing the business access effects.

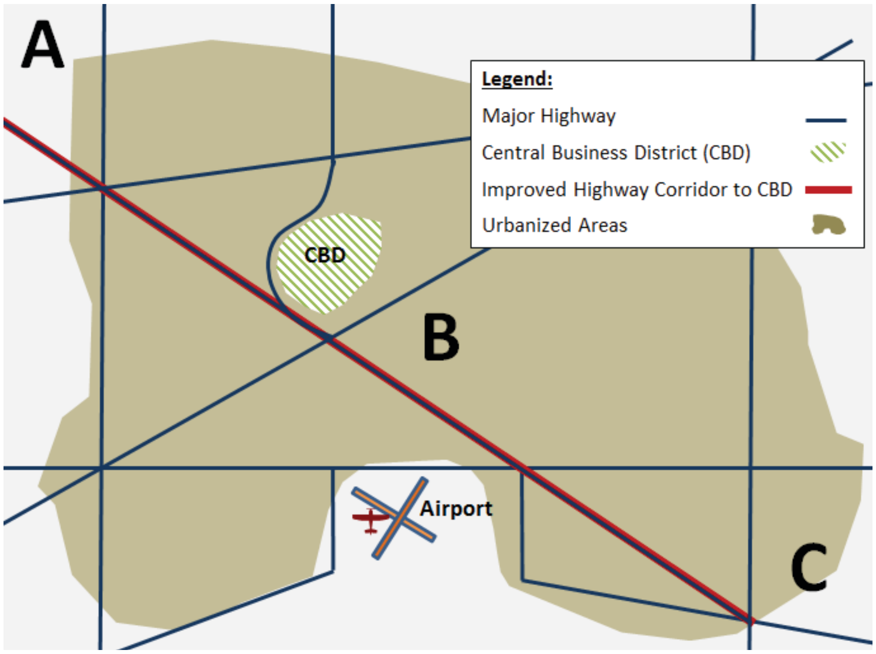


Figure 4-2. Highway corridor example.

The assessment of STB in Step 3 accounts for both highway and transit modes. In Steps 4 and 5, the zone-to-zone travel times used to assess improvements to regional accessibility are minimum zone-to-zone travel time and therefore reflect *highway* travel times. In this case, the introduction of public transit in the build scenario improves highway travel times through mode switching effects. (See Figure 4-3.) The analysis process remains the same regardless of whether the access assessment is based on highway travel times or transit travel times.

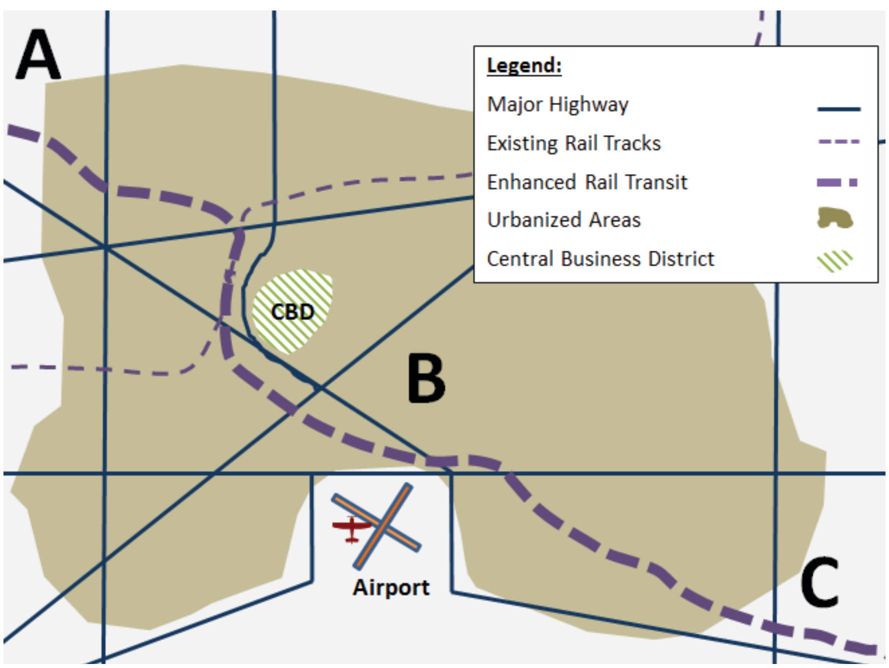


Figure 4-3. Public transit corridor example.

Step 1: Access Corridor—Initial Screening for Productivity Impacts

In Step 1, the analyst develops a profile of the project(s) under consideration and determines whether productivity analysis can, and should, be conducted. The project is classified using the Project Classification Form from Figure 3-1.

Project Classification Form

1. Project Name:	*Set of Highway/Transit Projects*
2. Project Facility Type:	*Highway/Road*
3. Project Objective:	*Travel Time, Metro Market Access, Business Access*
4. Project Impact Area:	*Urban/Metro Area*
5. Trip Purpose:	*Commuting, Business Travel, Freight Movement*

Based on the above classifications, the project is then assessed using the Screening Decision Table, which indicates that the set of projects is eligible for productivity impact analysis using available tools.

Step 2: Access Corridor—Selection of Applicable Tools

In Step 2, the Analysis Tool Selection Table (Table 3-2) is used to determine the types of transportation impact factors that can be analyzed, and the analysis tools available for measuring them. Based on the project objectives, an STB analysis will be calculated, along with an assessment using the market access tool (also called the Effective Density Access Tool). The project passes the associated thresholds for these tools:

- **Travel Time.** The threshold for travel time is an annual reduction in VHT greater than 100,000. Reduction in VHT obtained from a regional travel demand model is 3M annually and passes the threshold.
- **Metro Access (between Population and Employment).** The project area is an urbanized area (density over 1,800/square mile) with a population of 1.3M.
- **Business Access.** The threshold for assessing business access impact is that trucks account for more than 12 percent of vehicles on the roadway. Annual AADT data, available from the state DOT's traffic statistics website, shows a range of truck shared from 10 percent to 30 percent on major highways within the region. Therefore, most (but not all) links pass the truck percentage threshold.

Step 3: Access Corridor—Measurement of Transportation Changes

This step measures transportation changes in the highway and transit investment scenario, relative to a base case. The basic impacts of the project on transportation conditions are calculated as inputs to an STB analysis as shown. Table 4-11 summarizes the cost factors and vehicle loading assumptions used in the STB analysis.

Travel characteristics in the base and build cases are obtained from a travel demand model and summarized in Table 4-12. The build scenario results in speed improvements, mode switching to transit, and some induced demand on the highway network.

Adjustment for Induced Trips. Transportation changes are projected using a travel demand model, and include some prediction of induced trip making due to the improvements in regional access. To calculate the effect on productivity (cost per business trip), it is necessary to net out the effect of induced trips and just count the VHT and VMT savings for the volume of

Table 4-11. Access Corridor: Cost factors and vehicle loading for STB.

	Value of Time ($/Passenger Hour)	Value of Time ($/Crew Hour)	Vehicle Occupancy (Not Including Crew)	Crew per Vehicle	$/VMT
Passenger Car, Business	22.9	-	1.1	-	0.44
Passenger Car, Commute	12.0	-	1.1	-	0.44
Truck Freight	-	23.7	-	1	0.95
Bus, Business	22.9	26.4	10.5	1	1.52
Bus, Commute	12.0	26.4	10.5	1	1.52
Rail, Business	22.9	39.86	120	2	8.62
Rail, Commute	12.0	39.86	120	3	8.62

Note: All values of time, as well as occupancy, for passenger car and freight truck are based on Step 3 defaults presented in Chapter 3. All occupancy values for bus and rail transit are normally based on local data, although fictitious values are shown for this illustration.

pre-existing (base case) trips. The addition of induced trips should not dilute the productivity gain, nor should the consumer surplus associated with induced trips add to productivity gain. (The benefit of new trips enabled by access improvement will be captured in Step 4.) Table 4-13 presents a summary of travel characteristics, after netting out the effect of induced trips. Any remaining change in vehicle-trips, VMT, and VHT is due to mode switching and, in the case of transit, due to more efficient routing of new transit service. Note that if the travel characteristics had been developed using engineering estimates that did not predict induced trip making, this adjustment step would not have been required.

Adjustment to Represent Business Costs. For this case, productivity benefits are defined to include the costs of labor time and vehicle operations for work travel by car and truck. In addition, the incremental change in time and vehicle operating costs for commuting trips also are included, as they can affect wage premiums paid by employers to workers in the congested business district. Personal (non-commuting and non-business) time and vehicle operating cost savings are still excluded from this productivity analysis, since those costs are borne by households.

The impact in terms of vehicle-trips, VMT, and VHT are presented in Table 4-14 for passenger car commuters, business travelers, and truck freight. Note that the table is presented in terms of *vehicle* hours. To arrive at the number of passenger hours, one would multiply the VHT by the average vehicle occupancies in Table 4-14 (e.g., 1.1 for passenger cars and 120 for passenger rail). The travel demand model breaks out travel information for commuting and freight, but

Table 4-12. Access corridor: Travel characteristics (with induced trips, annual, in thousands).

Mode/Scenario	*Highway & Transit Build*		
HIGHWAY*	**Vehicle-Trips**	**VMT**	**VHT**
Base	63,286	459,092	15,172
Build	65,773	477,121	14,520
Build - Base	2,487	18,029	-652
TRANSIT**	**Vehicle-Trips**	**VMT**	**VHT**
Base	41	339	10
Build	65	485	14
Build - Base	24	146	4

*Includes car commute, car business, and truck freight (does not included personal trips);
**includes bus and rail commute/business trips (does not include personal trips).

Table 4-13. Access corridor: Travel characteristics (without induced trips, annual, in thousands).

	Highway + Transit Build		
Highway*	**Vehicle Trips**	**VMT**	**VHT**
Base	63,286	459,092	15,172
Build	63,035	457,259	13,916
Build - Base	-251	-1,833	-1,256
Transit**	**Vehicle Trips**	**VMT**	**VHT**
Base	41	339	10
Build	65	485	14
Build - Base	24	146	4

*Includes car commute, car business, and truck freight (does not included personal trips);
**includes bus and rail commute/business trips (does not include personal trips).

not for business travel. Therefore, based on 2009 NHTS estimates, it is assumed that 6.3 percent of total non-freight trips are for business. Note that a large share of the savings in this case is associated with worker commuting, in part because the transportation improvement (reduction in congestion) is greatest in the peak period.

The value of business cost savings for commute, truck freight, and business trips is calculated based on changes in VMT and VHT and the values in Table 4-11. The results are presented in Table 4-15.

Step 4: Access Corridor—Calculation of Wider Transportation Impacts

The parameters in Table 4-16 were used for the market access analysis. The analysis makes use of the market access tool. The corresponding inputs for the market access tool fall into the categories presented in Table 4-17.

Of these inputs, some are readily available with and without a model, while others will pose more of a challenge for users who do not have a model available.

With a Travel Demand Model

- **Impedance.** Impedance values between zones are obtained from travel demand models in the form of travel time skim matrices. Assignments from travel demand models have the advantage of being able to produce travel times that take into account redistribution of trips that affect travel times.

Table 4-14. Access corridor: Change in VMT and VHT (annual, in thousands).

	Highway + Transit Build		
Mode and Purpose	**Change in Vehicle Trips**	**Change in VMT**	**Change in VHT**
Car, Business	-18	-133	-324
Car, Commute	-233	-1700	-727
Truck Freight	0	0	-206
Bus, Business	1.70	10.54	0.30
Bus, Commute	21.56	133.83	3.81
Rail, Business	0.02	0.14	0.004
Rail, Commute	0.25	1.63	0.05

Table 4-15. Access corridor: Value of annual VMT and VHT savings (in $ thousands).

	Highway + Transit Build	
Mode and Purpose	**VMT Savings**	**VHT Savings**
Car, Business	58	8,159
Car, Commute	748	9,592
Freight Truck	0	4,875
Bus, Business	-16	-80
Bus, Commute	-203	-581
Rail, Business	-1	-11
Rail, Commute	-14	-72
Total with Commuting	572	$21,881
Total without Commuting	41	$12,943
	Annual Total Savings	
With Commuting	$22,453	
Without Commuting	$12,984	

Table 4-16. Access corridor: Market access analysis parameters.

Parameter	Value	Comment
1. Constant Decay Factor, α	1	This exponent reduces the attraction of other zones as the generalized cost of travel to them (from any given zone) increases
2. Base Year (No-Build Year)	2040	Both the build and no-build cases are compared for a future year
3. Reference Year (Build Year)	2040	
4. Productivity Elasticity	0.04	Recommended value for freight truck travel and manufacturing industries (Table 3-9)
5. Calculate	Effective Density	

Table 4-17. Access corridor: Inputs to market access tool, by category.

Category	Specific inputs Used
Network link characteristics (e.g., time, cost)	Impedance: Interzonal matrix (generalized cost)
Zonal characteristics (population, employment)	Activity: Place of work employment data
Labor force (e.g., employment, wages)	GRP: may be estimated based on annual income (GRP is typically 1.5 to 3 times wage income, depending on the mix of industries present)

This analysis uses simplified travel time skims from the regional travel demand model, aggregated to the 15 zones that were defined to capture the expected accessibility impacts. Using the travel demand model skims enables the analyst to account for a full range of network connectivity effects caused by the set of projects under consideration.

- **Activity information.** This information is readily available, and zonal population and employment data is used to calibrate travel demand models and therefore can be readily sourced from such a model. This demonstration uses zonal employment from an MPO travel demand model. Activity levels are held constant between the base and build years in order to isolate the effects of access changes alone.
- **GRP.** Since GRP information is not measurable or available for zones smaller than MSAs, average annual wages are used as a proxy for each of the 15 zones (based on the theory that wages reflect differences in productivity across a metropolitan area). This data is obtained from the MPO travel demand model. An adjustment factor is applied to account for the ratio between output and total wages in a region.

Without a Travel Demand Model

- **Impedance.** Without a travel demand model, simplifying assumptions were made to develop estimates of travel times between zones for no-build and build scenarios. First, the number of zones was reduced to three. Second, changes in travel times were estimated based on a list of major highway projects and their expected impacts.
- **Definition of Zones.** The study region is comprised of a more urbanized central region that includes the primary CBD, and two additional regions to the north and south that are a mix of residential and employment centers. The primary highway investments under consideration are oriented north–south, improving accessibility within and between each of these three regions.

  Figure 4-4 depicts the simplified zones and major highway capacity projects. On the left is a map of the 15 zones used in the travel demand model process with the 3 aggregated zones overlaid on top. On the right is a network map with major capacity expansion projects labeled. The CBD is located in the central zone (B).
- **Estimates of Impedance (Changes in Travel Times).** Base case (no-build) travel times were calculated between representative locations within each of the three zones, using Google Maps, as presented in Table 4-18.

Then, based on knowledge of the major highway projects, assumptions are made about the percent reduction in travel times for each origin-destination pair (Table 4-19).

- **Time Savings.** The most significant time savings are assumed for trips either within the southern zone (C) or between the central zone (B) or northern zone (A) and the southern zone (C). The assumed travel time reductions are used to calculate a build impedance matrix of interzonal travel times.
- **Activity.** Without a model, base year data can be obtained from the Longitudinal Employer-Household Dynamics (LEHD), using the “OnTheMap” tool. A statewide employment growth rate of 2.7 percent per year is then used to generate numbers for the year 2040.

  Again, activity levels are held constant between the base and build years in order to isolate the effects of access change alone.
- **GRP.** Average per employee GDP for the MSA is used as a proxy for zonal GRP.

Step 5: Access Corridor—Calculation of Direct Productivity Elements

The access tool calculates an effective density for each zone, calculated as the sum of impedance-weighted activity opportunities in outside zones. This is aggregated across all zones in the region to represent a regionwide measure of effective density. The results from the tool’s calculations are summarized in Tables 4-20 and Table 4-21. Note that the magnitude of the effective density scores differs between the model and no-model case. This is because the model-case aggregates

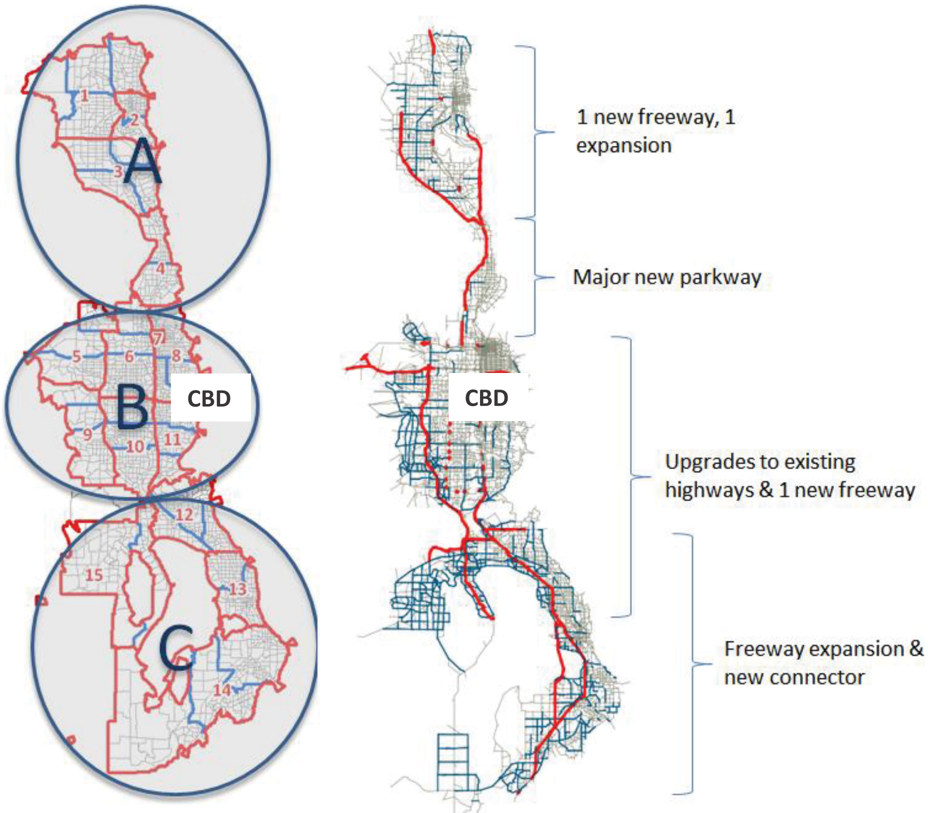


Figure 4-4. Access corridor: Simplified zones and major capacity projects (no-model estimates).

Table 4-18. Access corridor: Zone-to-zone travel base case travel times (estimates with no model available).

(Minutes)		DESTINATIONS A	B	C
ORIGINS	A	20.00	45.00	55.00
	B	45.00	20.00	50.00
	C	55.00	50.00	35.00

Table 4-19. Access corridor: Percent reductions in travel time due to major highway projects (no-model estimates).

	A	B	C
A	-5%	-6%	-7%
B	-6%	-5%	-10%
C	-7%	-10%	-12%

Table 4-20. Access corridor: Effective density results (estimates with model).

Zone	No Build 2040	Build 2040	(A) Accessibility Index	(B) % Change in Output Due to Δ Market Access (%)	(C) Zonal GDP in $ Billions	(D) Productivity Impact in $ Millions
	Effective Density	Effective Density				
1	18555	18818	1.01	0.06	2.816	1.586
2	29056	29449	1.01	0.05	2.888	1.552
3	28196	28635	1.02	0.06	4.741	2.931
4	40550	42485	1.05	0.19	2.719	5.075
5	45923	47761	1.04	0.16	1.409	2.215
6	20509	21677	1.06	0.22	6.707	14.878
7	67417	69836	1.04	0.14	1.098	1.550
8	13863	14426	1.04	0.16	7.368	11.743
9	36928	41541	1.12	0.47	2.473	11.674
10	17221	18334	1.06	0.25	7.360	18.462
11	25335	26818	1.06	0.23	5.321	12.122
12	22140	23393	1.06	0.22	5.051	11.135
13	17142	17958	1.05	0.19	7.157	13.327
14	11422	12103	1.06	0.23	3.958	9.181
15	29623	32909	1.11	0.42	2.326	9.812
TOTAL	**423,880**	**446,143**			**63.392**	**127.243**

(A) Accessibility index = (effective density build)/(effective density build); (B) % change in output = [(accessibility index)^0.05]-1; (C) zonal GDP is the zonal per employee GDP proxy multiplied by the zonal employment; (D) total productivity = % change in output x zonal GDP

generalized cost between all zones for 15 zones (225 pairs) while the simplified no-model case uses only 3 zones (9 pairs). Effective density is a relative measure; percent change in effective density is the variable of interest for determining productivity changes.

With a Travel Demand Model

Table 4-20 summarizes the changes in accessibility associated with the build scenario. Faster effective speeds between zones lead to expanded effective market access, which is represented in terms of higher effective density values in the build case. The accessibility index, a ratio of effective densities in the build and no-build cases, captures the increases in vehicular accessibility that result from the set of projects. For this step, the value (in $) of expanded market access is represented as an increase in business output. It is calculated by applying an output elasticity value (of 0.04 for freight and manufacturing industries, from Table 3-9) to the percentage growth in market accessibility for regional firms, on a zone-by-zone basis as shown in Table 4-20.

Table 4-21. Access corridor: Effective density results (no-model estimates).

Zone	No Build 2040	Build 2040	(A) Accessibility Index	(B) % Change in Output Due to Market Access (%)	(C) Zonal GDP in $ Billions	(D) Total Productivity Impact in $ Millions
	Effective Density	Effective Density				
A	17338	18394	1.06	0.24	11.886	28.145
B	25471	26926	1.06	0.22	39.666	88.240
C	13820	15328	1.11	0.42	11.846	49.178
Total	56,629	60,648			63.398	165.563

(A) Accessibility index = (effective density build)/(effective density build); (B) % change in output=[(accessibility index)^0.05]-1; (C) zonal GDP is the zonal per employee GDP proxy multiplied by the zonal employment; (D) total productivity = % change in output x zonal GDP.

Table 4-22. Access corridor: Effects on productivity, highway and transit build scenario.

Productivity Factor for Affected Business Firms	With Travel Model	No Travel Model
Annual Business Output (Value Added, in Millions)	$127.2 Increase	$165.6 Increase
Annual Business Operating Cost (Millions)	Savings of $13.0 ($22.5)	

Note: Annual business operating cost does not include savings for commute trips. The number in parentheses reflects adjusted total that includes commuting savings to account for wage premium effects that apply under certain conditions.

Without a Travel Demand Model

Without the model, the tool estimates effective densities for each of the three zones, with and without the major highway projects analyzed, as presented in Table 4-21. These intermediate values are then transformed into output growth in the same way as with a travel demand model—by applying the same output elasticity value (0.04) to the growth in accessibility.

Effects on Productivity. While productivity is defined as the ratio of {business output/business operating cost}, the calculations show incremental changes in both the numerator (business output) and denominator (business operating cost) of that ratio. Results are summarized in Table 4-22 for the full build scenario, which includes both highway and transit investments.

Step 6: Access Corridor—Overall Productivity Results

Direct Calculation. Overall impacts on productivity must be placed in the context of a study area—which in this case may be either the entire metropolitan or the improved corridor and city center. A travel demand model is required to distinguish the location of trip ends and hence portion of modeled impacts that apply to the defined study area(s). So in this case, the corridor-level impacts are calculated on the basis of the portion of affected trip ends that are located in the corridor. Calculated results are shown in Table 4-23.

Table 4-23. Access corridor: Calculation of overall productivity results. *(numbers in parentheses include commuting-related savings)*

	Concept	Source	Regional Impact	Corridor Impact
	Study Area Metrics			
1	Employment Base	Given	650,000	156,000
2	Annual Wage Income	Given	$42.2 Billion	$12.7 Billion
3	GDP or GRP (representing GVA)	Given	$63.4 Billion	$38.2 Billion
4	Trip Ends Within the Study Area	Travel model	100%	64%
	Project Impact			
5	Change in Value Added from Revenue Growth	Note 1	+ $127 Million	+ $81 Million
6	Change in Value Added from Cost Reduction	Note 2	+ $13 Million ($22 Million)	+ $8 Million ($14 Million)
7	Total Change in Value Added	=Rows 5 + 6	+ $140 Million ($149 Million)	+ $90 Million ($95 Million)
8	% Change in Value Added from Rev. Growth	= Rows 5/3	+ 0.20%	+ 0.21%
9	% Change in Value Added from Cost Reduction	= Row 6/3	+ 0.02% (0.03%)	+ 0.02% (0.04%)
10	Total % Change in Value Added	= Row 7/3	+0.22% (0.24%)	+0.24% (0.25%)
11	Change in Value Added per Worker	= Rows 7/1	$215 ($229)	$577 ($609)
12	Change in Value Added per Wage Dollar	= Rows 7/2	.033 (.035)	.007 (.08)

Note 1: This value comes directly from the effect of increasing the effective density of the regional market (i.e., "agglomeration economies"), as calculated in Step 5. Note 2: This value comes directly from the change in business operating cost, as calculated in Step 3 and also shown in Step 5.

Key Findings from the Market Access Enhancement Case Study

1. This case study illustrated how productivity calculations are to be carried out for a situation in which there is a coordinated set of major multimodal (road and transit service) improvements along a corridor serving labor, delivery, and shopper markets for a major activity center. In general, the cases with the most productivity impact from market access improvements are cases in which a zone or set of zones achieve significant reductions in zone-to-zone impedances to other large centers of activity.
2. The scale of zonal economic activity directly affects the magnitude of the productivity impacts of market access improvements, given that the calculations are elasticity based.
3. The inclusion of market access (agglomeration) benefits expanded productivity benefits by a factor of 10 over what would otherwise be counted as business cost savings associated with commercial vehicles. Even when workforce access effects are counted by including savings for commute trips, the benefit is still increased over five-fold by the inclusion of agglomeration effects. This is due to the very large-scale nature of the project—a coordinated set of road and transit projects that enhances access across a long, cross-regional corridor.
4. Total productivity benefits are significant—potentially in the range of $100M or more per year and $600 per worker annually. However, the results are very sensitive to the selected study area definition, the elasticity value, and choice of the interzonal decay function selected in Step 4 (Table 4-16). Additionally, the methodology for calculating wider benefits from market access improvements is based on changes in access between areas, rather than the time savings for previously forecast trips between origin-destination pairs.
5. The basis for spatial comparison also matters. Moving the study area from the core impact corridor to a broader regionwide scale serves to slightly increase the total regional business output gain while substantially diluting the per capita productivity gain.
6. All impacts are relative; even when regional productivity gains exceed $100M per year, the gain in value added amounts to less than one-half of 1 percent of the region's total GVA (which is nearly the same as its GDP). Nevertheless, the inclusion of agglomeration benefits is significant in that it can potentially generate economic benefits larger than the user benefits counted in standard transportation benefit analysis.
7. This illustrative case focused on demonstrating how to estimate the regional scale (urbanization) economies associated with broadening market access across a metropolitan area. Very different results could occur for a project that enables supply chain integration (a technology impact) or other localization effects within a supply chain.

4.4 Example C—Intermodal Connectivity Enhancement

Summary of Key Inputs and Characteristics. This case assesses two categories of impacts associated with the construction of a new highway that will improve access to an airport: (1) reductions in overall travel time and cost and (2) broadening of the gateway function of the airport as a terminal for long-distance intermodal (truck/air) movements. Key data inputs are as follows:

(1) STB	(2) Wider Benefit from Enhanced Intermodal Connectivity
Change in VMT, VHT, and cost factors, by mode and trip purpose	Truck volumes, base and build airport access times, distance of improvement from airport (or fraction of truck traffic associated with airport)

In this example there is a proposal to construct a new highway to relieve congestion on an existing access highway to the airport by enabling the diversion of traffic between the CBD and a northern satellite city area (see Figure 4-5).

By removing traffic from the airport connector, access times to the airport from the CBD, as well as points north and south, will be enhanced. The benefits of enhanced intermodal connectivity can apply for both car-air intermodal passenger movements and truck-air intermodal cargo movements to and from the region.

Allowing more direct travel from a range of suburban areas can enable the airport to more effectively serve as a gateway from outside areas into the local region. Conversely, it can enable businesses in some parts of the region to more effectively access outside destinations.

This project can affect productivity in two ways. First, it can provide labor cost and delivery vehicle cost savings for movements to and from the airport—increasing labor and capital productivity. Second, it can effectively broaden the gateway function of the airport as a terminal for long-distance intermodal (ground/air) movements.

An important feature of this case is that it calls for a different type of assessment than STB analysis. A conventional analysis would calculate benefits in terms of the time savings for people and truck operators going to and from the airport. However, a conventional analysis would effectively stop at the airport gate and not consider whether there are additional economic implications of the project because of its effects on journeys and freight shipments going (or originating) much further afield.

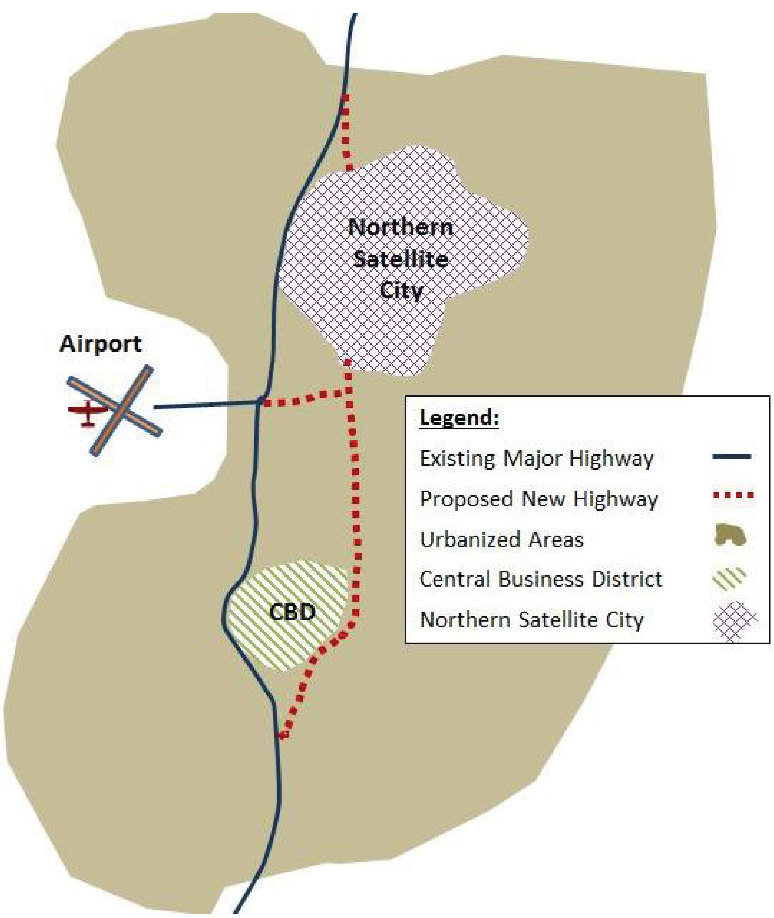


Figure 4-5. Highway and improved airport connector.

The intermodal connectivity analysis seeks to assess the added value of facilitating travel to/from other cities and regions. This illustrative example covers both car and truck time savings for Step 3 (STB), but focuses Steps 4 and Step 5 (broader productivity analysis) on the effects of improved truck access to the airport as an intermodal freight facility. The intermodal connectivity tool could as easily have been run to assess the effect of improved passenger vehicle access to the airport as a gateway to outside areas.

It is also important to note that while this example deals with construction of a new highway to divert traffic from an existing airport connector and relieve congestion, the same improvements in access could be achieved by other types of projects, including the construction of an entirely new airport access road.

Step 1: Airport Terminal—Initial Screening for Productivity Impacts

The project is classified using the Project Classification Form (from Figure 3-1).

Project Classification Form

1. Project Name:	*New Highway and Airport Access Improvements*
2. Project Facility Type:	*Highway/Road*
3. Project Objective:	*Intermodal Connectivity*
4. Project Impact Area:	*Urban/Metro Area*
5. Trip Purpose:	*Freight Movement*

Based on the above classification, the project is assessed using the Screening Decision Table, which indicates that the project is a candidate for productivity analysis using available tools.

Step 2: Airport Terminal—Selection of Applicable Tools

In Step 2, the Analysis Tool Selection Table (Table 3-2) is used to determine the types of transportation impact factors that can be analyzed, and the analysis tools available for measuring them. The project improves access to an intermodal terminal, and it passes the threshold factor for use of the intermodal connectivity tool. The project also passes the threshold for VHT reduction. The expected change in VHT is greater than 100,000 annually.

With a Travel Demand Model

In the travel demand model, the share of truck freight vehicle-trips on the corridor is 6 percent, along with a 20 percent share for commuter trips. Therefore, given that this is a highway that also carries a considerable amount of commuter traffic, the Intermodal Connectivity Tool is an appropriate tool for conducting this productivity analysis.

Without a Travel Demand Model

Annual AADT data based on traffic counts is available for download from the state DOT's traffic statistics website. This data shows a range of truck percentages at different locations along the corridor from 5 percent to 20 percent, thus confirming that the Intermodal Connectivity Tool is appropriate for this analysis.

Step 3: Airport Terminal—Measurement of Transportation Changes

In Step 3, the basic impacts of the projects on transportation conditions are calculated as inputs to an STB.

Table 4-24. Airport terminal: Travel characteristics (with a model, daily).

Scenario	Vehicle Trips	VMT	VHT
Base	627,968	9,419,520	285,440
Build	502,374	7,535,616	125,594
Build - Base	-125,594	-1,883,904	-159,846

Note: The above numbers include personal trips that will not be included in the subsequent productivity analysis.

With a Travel Demand Model

Travel characteristics in the base and build cases are presented in Table 4-24, as obtained from a travel demand model. In the build case, some trips are diverted from the airport connector to the newly constructed highway. This results in reductions in both VMT and VHT on the existing airport connector. In addition, VHT savings accrue to the remaining trips, due to reductions in congestion. The VMT and VHT reductions associated with the diverted trips do not represent "real" business cost savings at the regional level because the diverted trips will accrue VMT and VHT elsewhere in the region. For the calculations of STB, this analysis considers only the time savings that accrue to users who remain on the existing airport connector. Should one wish to do a more comprehensive regional analysis, a regional model would be required to predict the VMT and VHT of diverted trips.

Adjustment to Represent Business Costs. Valuation of the VMT and VHT for the purpose of a productivity analysis depends on whether savings accrue to car commuters, car business travelers, or trucks used for freight. Personal (non-commuting and non-business) trips are excluded for the purpose of a productivity analysis. Truck freight and car business effects are direct business costs. The car commute element can be applicable to the extent that commuting to the airport area, or commute trips that pass by the airport area, are affected. In those cases, there also can be a resulting impact on wage compensation for the affected classes of trips. All per unit valuations for VMT and VHT are drawn from Table 3-5.

The impact in terms of VMT and VHT are presented in Table 4-25 for passenger car commuters, business travelers, and truck freight. There are no changes in VMT associated with the non-diverted trips, thus all changes are related to time savings. The travel demand model breaks out travel information for car commuting and truck freight, but not for business travel. Therefore, it is assumed based on 2009 NHTS estimates that 6.3 percent of total car trips are for business.

The value of business cost savings was calculated by vehicle type and trip purpose, based on changes in VMT and VHT (using the values in Table 3-5). The results are presented in Table 4-26. Note that all savings for the non-diverted trips are associated with VHT changes, not with a change in VMT.

Table 4-25. Airport terminal: Change in VMT and VHT associated with non-diverted trips (with a model, annual, in thousands).

Mode and Purpose	Change in VMT (Build - Base)	Change in VHT (Build - Base)
Passenger Car, Business	0	-1,591
Passenger Car, Commute	0	-5,343
Truck Freight	0	-1,469

Table 4-26. Airport terminal: Value of annual VMT and VHT savings for non-diverted trips (with a model, in millions of dollars).

With Model	Annual Savings ($ Millions)	
Mode and Purpose	VMT Savings Value	VHT Savings Value
Passenger Car, Business	0	40.07
Passenger Car, Commute	0	70.53
Truck Freight	0	34.83
Total with Commuting	0	145.43
Total without Commuting	0	74.89
	Annual Total Savings	
With Commuting	145.43	
Without Commuting	74.89	

Note: The truck freight and car business effects are direct business costs; the car commute element reflects an effect that occurs under certain conditions on wage compensation as the commuting cost to a specific area changes.

Without a Travel Demand Model

Without a model, the estimates in Table 4-27 were developed, based on current trip counts and the following assumptions:

- Diversion of 20 percent of current trips from the airport connector to the new highway,
- An average trip length of 20 miles, and
- A base-case speed of 40 mph and a build speed of 60 mph.

The impacts in terms of VMT and VHT are presented in Table 4-28 for passenger car commuters, business travelers, and truck freight. As before, business travel is assumed to account for 6.3 percent of total car trips. There are no changes in VMT associated with the non-diverted trips, thus all changes are related to time savings.

The value of business cost savings was calculated for changes in VMT and VHT using unit values shown earlier in Table 3-5. The results are presented in Table 4-29. The no-model case yields different estimates of VHT savings due to the difference in assumptions about no-build and build average speeds. Again, note that all savings for the non-diverted trips are associated with VHT changes, not VMT.

Step 4: Airport Terminal—Calculation of Intermediate Factors

To calculate the project's effect on intermodal connectivity, the tool is run twice—once using the base travel time to the airport via the highway, and once with the new reduced travel time.

Table 4-27. Airport terminal: Travel characteristics (without a model, daily).

Scenario	Vehicle Trips	VMT	VHT
Base	627,968	12,559,360	313,984
Build	502,374	10,047,488	167,458
Build - Base	-125,594	-2,511,872	-146,526

Note: the above numbers include personal trips that will not be included in the subsequent productivity analysis.

Table 4-28. Airport terminal: Change in VMT and VHT associated with non-diverted trips (without a model, annual, in thousands).

Mode and Purpose	Change in VMT (Build - Base)	Change in VHT (Build - Base)
Passenger Car, Business	0	-1,296
Passenger Car, Commute	0	-4,354
Truck Freight	0	-1,197

With a Travel Demand Model

The input data (Table 4-30) is assembled and computed as follows:

- Distance calculations are based on network information from a travel demand model.
- The number of trucks using the highway facility is obtained from the baseline data within a travel demand model.
- Hours per Truck—Base is the travel time on the highway in the no-build scenario, from the travel demand model.
- Hours per Truck—Build is the travel time on the highway in the build scenario in which a new parallel highway has been constructed thereby relieving congestion on the existing facility. The values are obtained from a travel demand model run and therefore account for a full set of network connectivity and diversion effects.

Without a Travel Demand Model

The input data is assembled and computed as follows:

- The Web-based mapping tools of Google, Yahoo, Bing, or MapQuest maps are used to calculate distance of the improvement from the airport.
- The number of trucks is obtained from HPMS data or local traffic counts.
- Estimates of time savings are developed based on knowledge of existing congestion and travel on the highway and an assumed diversion of traffic from the existing highway to the new facility. For example, with an assumed 20 percent diversion of traffic from elsewhere, the reasonable engineering estimates may be as shown in Table 4-31.

In addition to the inputs from the users, the tool also calculates a fraction of truck traffic on the highway facility that is actually associated with the airport (0.7 in this case). The calculation

Table 4-29. Airport terminal: Value of annual VMT and VHT savings for non-diverted trips (without a model, in millions of dollars).

With Model	Annual Savings ($ Millions)	
Mode and Purpose	VMT Savings Value	VHT Savings Value
Passenger Car, Business	0	32.65
Passenger Car, Commute	0	57.47
Truck Freight	0	28.38
Total with Commuting	0	118.50
Total without Commuting	0	61.02
	Annual Total Savings	
With Commuting	118.50	
Without Commuting	61.02	

Note: The truck freight and car business effects are direct business costs; the car commute element reflects an effect that occurs under certain conditions on wage compensation as the commuting cost to a specific area changes.

Table 4-30. Airport terminal: Intermodal connectivity tool inputs (with travel model).

With a Travel Model Inputs to Intermodal Connectivity Tool	Model Value
Distance of Improvement from Facility (Miles)	7
Total Number of Trucks per Year using the Improved Highway Segment	8,979,942
Hours per Truck — Base	0.45
Hours per Truck — Build	0.25

assumes that the further away a section of road is from the airport, the lower the fraction of total trucks actually associated with airport-related activity.

Step 5: Airport Terminal—Calculation of Direct Productivity Effects

The intermodal connectivity tool calculates a statistical index that reflects the average travel time to access any given intermodal terminal (e.g., an air cargo port) and the magnitude of connecting services to outside origins and destinations that can be accessed from it. By multiplying the percent change in this index by an appropriate elasticity factor one can then calculate a percent productivity increase resulting from a change in accessibility to a given intermodal terminal.

Note: Since the connectivity tool results are scaled by travel time (or generalized cost), an improvement in access to an intermodal terminal shows up as a decrease in the rating value. Since the tool is run twice (with before-and-after travel times) to derive the change in access, the resulting measure of weighted connectivity actually goes down. The economic benefit results are, nevertheless, correct.

The tool is not set up to assess induced trip making from connectivity improvements. Therefore, the number of trucks per year using the facility and the fraction of truck traffic associated with the airport should not be changed between the base and build cases.

With a Travel Demand Model

Table 4-32 presents the outputs from the tool, using the inputs from a travel demand model. To calculate the value (in $) of expanded connectivity (expressed in terms of business output growth), the coefficient of elasticity for airports (value of 0.015, from Table 3-9) is multiplied by the percent change in the weighted connectivity score as shown in Table 4-33.

Table 4-31. Airport Terminal: Derivation of intermodal connectivity tool inputs (no-model estimates).

Without a Travel Model Inputs to the Intermodal Connectivity Tool	Estimated Value
Current Volume-to-Capacity Ratio on Highway	0.95
Future Volume-to-Capacity Ratio	0.76 (20% of traffic is diverted elsewhere)
Assumed Change in Speed	40 mph – 60 mph
Assumed Average Trip Length	20 miles
Hours per Truck — Base	0.5
Hours per Truck — Build	0.33

Table 4-32. Airport terminal: Intermodal connectivity tool outputs (with model).

	Base	Build
Total Trips on the Access Route (Annual)		
Number of Annual Trucks on Access Route	8,979,942	8,979,942
Total Truck Hours (All Trucks)	4,040,974	2,244,986
Total Value of Truck Hours	$230,043,329	$127,801,849
Trips Associated with the Intermodal Terminal (Annual)		
Number of Trucks Associated with Facility	6,084,907	6,084,907
Time Associated with Facility	2,738,208	1,521,227
Value of Time for Facility	$155,879,870	$86,599,928

Without a Travel Demand Model

Table 4-34 presents the outputs from the Intermodal Connectivity Tool, using the no-model inputs. Again, the value (in $) of expanded connectivity (expressed in terms of business output growth) is calculated by multiplying the coefficient of elasticity for airports (0.015, from Table 3-9) by the percent change in the weighted connectivity score (Table 4-35).

Effects on Productivity. While productivity is defined as the ratio of {business output/business operating cost}, the calculations show incremental changes in both the numerator (business output) and denominator (business operating cost) of that ratio. Results are summarized in Table 4-36.

Step 6: Airport Terminal—Overall Productivity Results

Direct Calculation. In this case, the productivity gain comes from two factors: (1) business cost savings in transportation-related costs due to a faster travel time plus (2) the effect of greater intermodal connectivity, which reflects improved access to the airport facility and improved ground-air connectivity enabled by it. These results are shown in Table 4-37.

Key Findings from the Market Access Enhancement Case Study

1. This case study illustrated how productivity calculations are to be carried out for a situation in which there is improved access to an intermodal terminal—in this case a new highway that relieves congestion on the existing airport access road and that also opens up access for a satellite city at (or beyond) the outskirts of the metropolitan area.
2. The key drivers of productivity impacts from improved intermodal connectivity are the number of trucks using the airport and the percent change in access times from the improvement.

Table 4-33. Airport terminal: Calculation of business output change due to improved intermodal connectivity (with model).

Facility Connectivity Raw Value	15.5
Value of Time for Accessing Facility - Base	$155,879,870
(Connectivity Raw Value) x (Value of Time - Base)	2,416,783,978.5
Value of Time for Accessing Facility - Build	$86,599,928
(Connectivity Raw Value) x (Value of Time - Build)	1,342,657,765.8
Percent Change in Connectivity Index**	44%
Change in Business Output Due to Improved Intermodal Connectivity	**0.015 * 0.44 = 0.007 [0.7% change in Business Output]**

Note: All values are based on annual data; **represents [-1 x (build - base)/base].

Table 4-34. Airport terminal: Intermodal connectivity tool outputs (no model).

	Base	Build
All Trips on the Access Route (Annual)		
Number of Annual Trucks on Access Route	8,979,942	8,979,942
Total Truck Hours (All Trucks)	4,489,971	2,963,381
Total Value of Truck Hours	$255,603,699	$168,698,441
Trips Associated with the Intermodal Terminal (Annual)		
Number of Trucks Associated with Facility	6,084,907	6,084,907
Time Associated with Facility	3,042,453	2,008,019
Value of Time for Facility	$173,199,856	$114,311,905

Table 4-35. Airport terminal: Calculation of business output change due to improved intermodal connectivity (no model).

Facility Connectivity Raw Value	15.5
Value of Time for Accessing Facility - Base	$173,199,856
(Connectivity Raw Value) x (Value of Time - Base)	2,685,315,531.7
Value of Time for Accessing Facility - Build	$114,311,905
(Connectivity Raw Value) x (Value of Time - Build)	1,772,308,250.9
Percent Change in Connectivity Index**	34%
Change in Business Output Due to Improved Intermodal Connectivity	0.015 * 0.34 = **0.005** **[0.5% change in Business Output]**

Note: All values are based on annual data; **represents [-1 x (build - base)/base].

Table 4-36. Airport terminal: Effects on productivity.

Productivity Factor for Affected Business Firms	With Travel model	No Travel Model
Annual Business Output (Value Added)	0.7% increase	0.5% increase
Annual Business Operating Cost	Savings of $74.89 Million	Savings of $61.02 Million

Note: Annual business operating cost does not include savings for commute trips.

Table 4-37. Airport terminal: Calculation of overall productivity results.

	Concept	Source	Airport and Access Route Impact
	Study Area Metrics		
1	Employment Base	Given	59,657
2	Annual Wage Income	Given	$4.8 Billion
3	GDP or GRP (Representing GVA)	Given	$7.1 Billion
4	Trip Ends Within the Study Area	Travel Model	95%
	Project Impact		
5	Change in Value Added from Revenue Growth	= Rows 8 * 3	47.22 Million
6	Change in Value Added from Cost Reduction	Note 1	$71.15 Million
7	Total Change in Value Added	= Rows 5 + 6	$118.37 Million
8	% Change in Value Added from Rev. Growth	Note 2	+ 0.67%
9	% Change in Value Added from Cost Reduction	= Row 6/3	+ 1.0%
10	Total % Change in Value Added	= Row 7/3	+ 1.7%
11	Change in Value Added per Worker	= Rows 7/1	$1,984
12	Change in Value Added per Wage Dollar	= Rows 7/2	0.02

Note 1: This value comes directly from the change in business operating cost due to time savings, as calculated in Step 3 (also shown in Step 5). It is adjusted downward to account for the fraction of trip ends that are within the study area (Line 4).
Note 2: This value comes directly from the effect of increasing the intermodal connectivity to the airport, which reflects improved access to the facility and ground-air connectivity enabled by it. It is adjusted downward to account for the fraction of trip ends that are within the study area (Line 4).

3. The improvement of intermodal connectivity affects productivity by enabling both business cost savings and expanded business markets (revenue growth). Both can be significant; in this case in the range of $118M annually—with expanded business activity accounting for over one-third of the total incremental productivity benefit.
4. In this case, the study area was defined as being sharply focused on the airport and adjacent satellite city, since the benefits were concentrated there. That focus helps to illuminate and calculate productivity benefits that might otherwise be diluted by the selection of an overly broad study area.

CHAPTER 5

Tools for Assessing Wider Transportation Effects

Transportation agencies differ widely in their analysis resources and capabilities. This chapter is designed to provide tools and guidance for agencies across the spectrum—from those that have no travel demand models to those with sophisticated transportation, land-use, and economic models. In all cases, the methods and tools described here are intended to demonstrate how wider transportation and economic impacts can be calculated. Although spreadsheet tools are presented, individual agencies are encouraged to adapt and modify these tools and methods as appropriate for their own uses.

A common feature of the tools and methods discussed in Sections 5.1 through 5.4 is that they rely upon forms of transportation system performance and traffic zone information that are commonly available to transportation agencies. No further information is required on the types of businesses that stand to benefit from proposed transportation projects. However, it is noted that the addition of information on the types of business areas served and freight being carried can enable sharper distinctions between projects in terms of their relative impacts on productivity. Sections 5.5 and 5.6 discuss optional tools that enable a more complete analysis of productivity benefits and impacts.

5.1 Use of Travel Demand Models

The analysis process outlined in Chapter 2 requires data on travel volumes and the performance of highway or transit links. This represents a challenge, given the wide differences in travel demand modeling capabilities among state DOTs and MPOs. Some agencies have sophisticated traffic simulation models, others have standard four-step transportation modeling systems, and still others have no formal models but rely on engineering estimates to generate transportation impacts. This chapter discusses the implications of different agency modeling capabilities.

Agencies with a Four-Step Travel Demand Model

Agencies with travel demand and network modeling capabilities can derive the STBs addressed in Step 3. Measures of aggregate changes in vehicle or trip rates, VMT, and VHT are typically generated by the models. Safety impacts can be calculated based on information about link volumes, link type categories, and average collision and injury incidence rates by mode and link type.

With travel models, an agency also can potentially derive most or all of the core data required for analysis of wider transportation impacts such as reliability, accessibility, and intermodal connectivity. To do so, the following issues should be addressed:

- It is important to distinguish traffic conditions on each relevant link for multiple peak and off-peak time periods, because the reliability metrics depend in part on volume/capacity ratios (which can vary tremendously over the course of a day).

- It is important to distinguish the truck percentage of traffic on each relevant link, since much of the reliability effect on productivity is derived from truck delays that trigger added costs of safety stocks and stranded inventory, as well as loading dock overtime.
- Market access measurement depends on forecasts of project impacts on trip volumes, travel times, and costs between zonal pairs, which can be readily calculated with travel demand models. It is important to separate out the effects of induced traffic volumes in a travel demand model, since market access (agglomeration) effects related to scale economies can generate additional traffic that should be distinguished from traffic growth due to travel time savings alone.
- To correct the induced traffic and market access interactions, it may be desirable to incorporate reliability effects into the measure of generalized costs between zones in the travel demand modeling process.
- Intermodal connectivity measurement can be enabled by identifying the zonal location of intermodal terminals, and then using network skims to calculate the times, distances, and costs of ground travel to those terminals from surrounding zones. Additional information on connecting air, marine, and rail services is embedded within the intermodal connectivity tool.

Note: In the long run, travel models can be enhanced to more directly value the unique challenges of intermodal connectivity. For example, it is challenging for a model of one urban area to take into account the extra value (and economic gains) that result from better access to an air or rail freight terminal that provides better access to more distant areas. One idea is to treat intermodal terminals as transportation network nodes with added trip attraction, since improved access to those nodes generates higher benefits. However, the implications for trip distribution are unclear.

Agencies with No Travel Demand Model

Many rural regions and some rural states do not have travel demand models because the road network and population settlement pattern is sparse. As a result, there is a limited likelihood of travelers switching routes, modes, or destinations. In these cases, a travel demand model is simply not justified. STBs may simply boil down to the following calculation where the cost saving may include the value of travel time, expense, and safety changes:

$$Benefits = Cost\ Saving\ per\ Vehicle \times Traffic\ Volume$$

Yet, that does not mean that rural transportation projects have no further effects on business productivity or economic competitiveness. There are several counter examples. One is a transportation investment intended to improve reliability by making the highway or railroad less prone to closure by snow or flooding. Another example is a package of improvements to highway geometrics that reduce or eliminate sporadic delays caused by large trucks blocking traffic when making wide turns. An additional example is a project to redesign at-grade railroad crossings to eliminate sporadic traffic backups when large freight trains block the road.

In all of these examples, it is possible to apply sketch planning methods that involve spreadsheets to assess route, mode, and destination shifts when there are only a handful of origin and destination zones. That approach is likely to be sufficient for intermodal connectivity as well as STB measures. Engineering estimates may be utilized to estimate project impacts on average peak period delays and required buffer times for the reliability analysis. In addition, external GIS systems or planner estimates may be used to enable simple spreadsheet calculations of market access benefits, as long as the number of zones is very small (as illustrated in the access case study in Section 4.3).

Agencies with an Activity-Based Model

Some large MPOs have moved toward activity-based modeling (ABM), which typically involves Monte Carlo micro-simulation to represent the choices made by a sample of travelers, and the constraints on those choices. Such methods have great potential to take account of factors such as the information available to the transportation users and the interpersonal and inter-temporal connections that affect their choices in ways that are impossible, or simply impractical, with conventional matrix-based models. While these methods may aid planning by providing more realistic scenarios, they raise questions for assessing the benefit of proposed projects.

These questions concern the data they provide and the use of micro-simulation. Each run of the model uses random numbers in forecasting choices, so the results from each set of inputs (such as a proposed highway improvement) reflect just one draw from a complex distribution. Ideally, the model should be run repeatedly to find the average results in the base and project cases, but it appears that this is not always done in practice. In addition, changing the seed values of the micro-simulation can alter the results when the model is run only a few times. This suggests that the seed file should be made consistent for the base and project cases and that the model should be run multiple times. As a result, there may be some concern that ABM, while valuable for understanding transportation behavior, may be less suitable for prioritization processes that call for calculating the productivity benefits of proposed projects.

5.2 Reliability Analysis Tools

The research team identified three spreadsheet-based tools that can be used for assessing reliability impacts of highway projects as part of a productivity impact calculation. All three were funded by the second Strategic Highway Research Program (SHRP2), administered by the Transportation Research Board. Each has a different intended use, and hence requires different types of inputs. The three reliability analysis tools are the C11 simplified reliability analysis tool for sketch planning, the L07 reliability analysis tool for highway project designs, and the L08 FREEVAL reliability analysis tool for freeway modeling. (Their letter-number designations are references to the corresponding SHRP2 Projects.) Key differences among them are summarized in Table 5-1.

Note that all three tools focus on road traffic characteristics, speeds, and effects of traffic incidents on queuing. As such, they are not applicable for other modes, although their basic designs may be of use in developing custom tools for other applications because the general concepts of delay incidents and queuing also apply for air, rail, and marine travel.

5.2.1 SHRP2—C11 Reliability Analysis Tool for Sketch Planning

Overview. The C11 Reliability Analysis Tool for Sketch Planning was developed by Cambridge Systematics and Weris (2013b) for SHRP2 Project C11. The tool and its manual are available for download at http://tpics.us/tools (see listing for "Reliability Tool.")

Table 5-1. Reliability analysis tools.

Spreadsheet Tool	Facilities	Traffic Data	Highway Designs	Freeway Simulation
C11 Tool for Sketch Planning	Road, Freeway	X		
L07 Tool for Project Designs	Road, Freeway	X	X	
L08 Tool for Freeway Simulation	Freeway Only	X		X

C11 is a spreadsheet designed to function as a sketch planning tool for highway capacity projects that have impact on both travel time and reliability. The tool estimates total delay costs and disaggregates them into recurring delay (i.e., travel time delay that is due to speed slowdown), and non-recurring delay (i.e., delay that follows random traffic incidents such as vehicle collisions and breakdowns). Costs associated with the non-recurring delay are referred to as reliability-related costs.

Operation. The foundation of the model is the use of travel time distribution functions estimated in SHRP2 Project L03. These travel time distribution functions are measured in terms of a travel time index (TTI), which is the ratio of average travel time under congested conditions divided by average travel time under free-flow conditions. The TTI distribution is truncated at a lower bound of 1, which represents vehicles traveling at free-flow speed. It is also truncated at a higher bound of 6, implying a vehicle speed of 1/6 of free-flow speed (e.g., a highway with free-flow speed of 60 mph functioning at only 10 mph). A TTI of 1.8 implies that vehicles take 80 percent longer to travel the route compared to if they traveled at the free-flow speed.

The initial calculations made by the model are intended to fit the TTI distribution for the local route. This is undertaken by estimating recurring travel time delay through the use of a generic speed/flow relationship and incident delay that is a function of the v/c ratio, number of lanes, and the length and type of time period. This allows the calculation of the mean TTI, as well as the calculation of other measures of the travel time index distribution (e.g., 80th or 95th percentile). Together, that data enables estimation of a generalized time equivalent measure of reliability for the route in question. From this measure, total delay costs can be calculated and then disaggregated into recurring delay and reliability costs.

Modal and Regional Coverage. The tool was developed for analysis of individual roadway links. It is most appropriately applied in cases where reliability impacts occur in discrete identifiable locations. (Using it to calculate reliability impacts for an urban network is cumbersome and requires extrapolating from the core of the underlying method to the model.)

Inputs and Outputs. To use this tool, users must specify a road link and then input the following information:

- Traffic data—Average annual daily traffic (AADT) and annual traffic growth rate (%);
- Truck data—Percent trucks in the traffic stream (combinations + single units);
- Capacity data—Peak capacity as determined with HCM procedures; and
- Road/highway data—Either the G/C ratio (effective green time divided by cycle length) for signalized highways, or type of terrain (flat, rolling, or mountainous) for freeways and rural two-lane highways.

Results are displayed for the base condition and improvement scenarios. Various reliability metrics are produced to allow users flexibility in interpreting the results. They also permit users to make independent estimates of the value of reliability if they want to use alternative measures of the reliability space.

- Delay—Recurring delay (hours), incident delay (hours), total delay (hours);
- Travel time index (TTI)—Overall, 95th percentile and 80th percentile;
- Percent of trips < 45 mph and < 30 mph; and
- Congestion Cost—Due to recurring delay, unreliability, and total.

Interpretation of Results. The recurring delay costs estimated by the reliability analysis tool correspond to the congestion delays estimated using STB analysis, which recognizes travel time delay impacts as well as vehicle operating cost and safety impacts. Therefore, the recurring delay costs should be removed from the delay estimated by the reliability analysis tool to avoid double counting. This also removes an element of delay costs not captured within STB analysis—that of expected delay due to traffic incidents. Since the reliability analysis tool does not separate out expected delay due to congestion from expected delay due to incidents, it is not possible to include the expected delays due to incidents specific to the facility in the estimate of the value of productivity impact (Step 5 in the prescriptive steps). However, the coefficients used to value safety savings include a national estimate of the delay costs associated with the average collision.

Impact on Productivity. Travel time and reliability costs will have a clear impact on productivity for business and commercial traffic (i.e., passengers traveling on employers' business and for trucks or freight). The tool separates commercial traffic from auto driver or passenger traffic, but does not separate auto driver or passenger traffic into business, commuting, and personal trips. To estimate the impact on productivity due to reliability benefits for business auto drivers and passengers, the analyst will need to adjust the output of the tool to identify the component of the total reliability benefits that will have an impact on business productivity. Typically, these costs will be estimated using a standard percentage of business travel. For example, the U.S.DOT guidance for valuing travel time in economic analyses (www.dot.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf) estimates 4.6 percent of trips are for business travel. This was derived from the 2001 National Household Travel Survey (NHTS). The 2009 NHTS estimates 6.3 percent of trips are for business travel.

5.2.2 SHRP2 L07 Reliability Analysis Tool for Design Treatments

Overview. The reliability analysis tool for design treatments was developed by HDR Engineering for SHRP2 Project L07. The tool and its manual are available for download at www.trb.org/StrategicHighwayResearchProgram2SHRP2/Pages/RFP_L38_Resources_and_Reference_Material_628.aspx. The tool was initially designed as a way to illustrate the benefits of various highway geometric design treatments on non-recurrent congestion. It has evolved into a practical sketch planning tool that allows the user to enter basic information about a corridor and to estimate likely reliability impacts.

The reliability analysis tool for design treatments is implemented as a spreadsheet with a customized (Visual Basic) user interface. The tool estimates travel time delay, reliability, and safety benefits for a specific design treatment. It also estimates the impacts on the travel time index (TTI) by hour and calculates other reliability measures of effectiveness, such as lateness index, standard deviation, buffer index, and semi-variance. This tool is more appropriate than the reliability analysis tool developed in SHRP2 Project C11 if a proposed improvement involves one of the 16 tailored design treatments programmed into the model.

Operation. Like the reliability analysis tool developed in SHRP2 Project C11, the design treatments tool estimates reliability impacts using relationships estimated in SHRP2 Project L03. Unlike the C11 analysis tool, the design treatments tool can estimate impacts for 16 tailored design treatments. The tool uses four variables to estimate reliability impacts: Critical Demand/Capacity Ratio (dc_{crit}), Lane Hours Lost (LHL), Hours with Rainfall Exceeding 0.05 Inches ($R_{0.05"}$), and Hours with Snowfall Exceeding 0.01 Inches ($S_{0.01"}$). For each tailored design treatment, the tool includes rule-of-thumb variable impacts estimated based on a literature review. These impacts are available under an assumptions option. The tool also allows the user to enter custom treatments by making manual changes in the four key variables.

Modal and Regional Coverage. The tool was designed to analyze individual roadway links with generally homogenous conditions (e.g., segments between successive interchanges). However, the tool can be used for a slightly larger segment if the highway geometry does not change drastically. It is best applied for discrete locations.

Inputs and Outputs. A graphical user interface (GUI) prompts the user to enter site-specific inputs using pull-down menus. In many cases, default values are provided. The site inputs are divided among the following tabs:

- Geometry—Basic information about the facility, its location, and geometry;
- Demand—Traffic demand date for each hour of the day including peak-hour factors and heavy vehicle percentages;
- Incident—Information about crash and non-crash incidents in terms of frequency, duration, and cost;
- Weather—Hourly rain and snowfall entered by the user or from 10-year average data for proxy sites included in tool;
- Event—Percent demand impacts of user-defined special events by hour of day; and
- Work Zones—Capacity impacts of short-term and long-term work zones by hour of day.

The model can be calibrated by adjusting default capacity figures. These are found in a hidden table that must be accessed using a password. Future revisions may allow the user to adjust capacity figures directly in the user interface.

The user can select up to 10 custom treatments for each site. For each treatment, the tool provides a tab where the user can enter detailed data, such as crash reductions and capacity improvements. For customized treatments, the user can model a project not included in the treatment list by adjusting one or all of the four variables used to estimate reliability impacts.

The tool includes a simple benefit-cost (or cost-effectiveness) analysis that takes into account the travel time, travel time reliability, and safety impacts of improvements. However, the model does not include information on demand growth. Lifecycle benefits are estimated from the base year benefits assuming a uniform series (i.e., future year benefits equal the base year).

The design treatments tool provides results using the following three tabs:

- Reliability Inputs—24-hour graphs for the four variables used to calculate reliability results, including Critical Demand/Capacity Ratio (dc_{crit}), Lane Hours Lost (LHL), Hours with Rainfall Exceeding 0.05 Inches ($R_{0.05''}$), and Hours with Snowfall Exceeding 0.01 Inches ($S_{0.01''}$);
- Travel Time Index (TTI)—24-hour, percentile, and single hour TTI graphs; and
- Reliability Measures of Effectiveness (MOEs)—Graphs showing impacts in terms of mean TTI, lateness index, standard deviation, semi-variance, 80th percentile TTI, planning time index (95th percentile TTI), misery index (97.5th percentile index), buffer index, skew statistics.

Interpretation of Results. The reliability component of the annual operational benefit estimated in the cost-effectiveness analysis corresponds to the user benefits of improved travel time reliability. This benefit is calculated by multiplying the change in the standard deviation of travel time by the value of reliability (i.e., the value of time multiplied by the reliability ratio). This estimate could be added to standard benefit-cost analysis without any double counting. Alternatively, the value of the reliability improvement can be estimated externally using the reliability MOEs reported for the treated and untreated conditions.

5.2.3 SHRP2 L08 FREEVAL-RL

Overview. The Institute for Transportation Research and Education (ITRE) at North Carolina State University developed FREEVAL-RL to estimate travel time reliability impacts using the freeway reliability analysis methodology developed in SHRP2 Project L08. The tool is based upon FREEVAL, a spreadsheet-based implementation of the 2010 Highway Capacity Manual (HCM) procedures for the operational analysis of under- and over-saturated freeway facilities. FREEVAL-RL and its manual are available for download at www.trb.org/StrategicHighwayResearchProgram2SHRP2/Pages/RFP_L38_Resources_and_Reference_Material_628.aspx.

FREEVAL-RL is a more sophisticated analysis tool than the reliability tools previously described. FREEVAL-RL is able to test the reliability impacts of projects by dynamically modeling multiple combinations of demand and operating conditions along a corridor using a Monte Carlo simulation (i.e., repeated random sampling). The tool allows users to model up to 70 highway segments along a single corridor. Each segment can vary from the next in terms of demand and highway geometry. The HCM methods in FREEVAL-RL allow the tool to estimate the traffic impact in each segment and traffic queuing to spread from one segment to the next.

Operation. Modeling travel time reliability in FREEVAL-RL starts with a seed file. This file contains information on the overall freeway corridor as well as the geometry and demand of individual segments along the corridor. This serves as the base run for the Monte Carlo simulation. The user defines scenarios for the Monte Carlo simulation in terms of demand multipliers, demand patterns, weather probabilities, and incident probabilities. These scenario inputs are used to generate and run multiple scenarios until the results converge.

The user is able to control the number of scenarios run and eliminate highly unusual (i.e., low probability) combinations of events. FREEVAL-RL summarizes the results of the scenario runs in terms of probability density functions, cumulative distribution functions, and other reliability performance measures for the facility. Since the tool uses Monte Carlo simulation, modeling freeway improvements can be very time consuming (i.e., several hours for a model run) and require relatively fast computer processors.

Modal and Regional Coverage. Unlike the other reliability analysis tools, FREEVAL-RL is able to model an entire freeway corridor. The tool has constraints in terms of the number of segments and time period modeled, but only very long or highly congested corridors will exceed these constraints. Regional impacts can be modeled by stringing together several corridor analyses. However, the impacts of one corridor on another cannot be taken into account, and FREEVAL-RL model runs can be very resource intensive.

Inputs and Outputs. To use this tool, users must develop a seed file with the following information:

- Seed File Management—Study period, analysis year, seed file demand, terrain type, ramp metering, and other corridor-level information; and
- Individual Segment Data—Length, number of lanes, segment demand, free-flow speed, capacity, percent trucks, adjustment factors, ramp demands, percent trucks on ramps, number of lanes on ramp, and ramp orientation.

The model uses scenario data, including the following, to generate the Monte Carlo runs:

- Demand Multipliers—Demand adjustments by month and day of week;
- Demand Pattern Configuration—Demand pattern adjustments for specific months and days of week;
- Weather Probability—Monthly occurrence of rain, snow, and low visibility conditions; and
- Incidence Probability—Detailed incidence data or estimates from "data poor" equations.

FREEVAL-RL generates analysis scenarios from the previous information. The user is given the ability to eliminate low probability scenarios from the analysis to save on model run time. Results are displayed in terms of several facility reliability performance measures, as follows:

- Travel Time Index (TTI)—Mean, 50th, 80th, and 95th percentiles;
- Misery index;
- Semi-standard deviation;
- Reliability rating; and
- Percent vehicle-miles traveled (VMT) at TTI > 2.

The tool also provides a summary of the percent contribution of recurring and non-recurring delays. Additional analysis details are provided to test model calibration.

Interpretation of Results. Unlike the other two reliability tools, FREEVAL-RL does not calculate a monetized value of travel time reliability benefits for inclusion in benefit-cost analysis. The user must calculate these values outside of FREEVAL-RL using one of the freeway reliability performance measures reported by the tool. The user would need to multiply the change in reliability (80th percentile TTI—50th percentile TTI or the change in the semi-standard deviation) by the value of reliability (value of time times the reliability ratio). The addition of travel time reliability benefits would not double count any benefits already included in standard benefit-cost analysis.

5.3 Accessibility Analysis Tools

The research team identified two spreadsheet-based tools that can be used for assessing the market access impacts of ground transportation projects as part of a productivity impact calculation. The effective density tool and fixed threshold tool were both funded by SHRP2, which is administered by the Transportation Research Board and programmed by Texas A&M University's Transportation Institute. These two spreadsheet-based tools illustrate how it is possible to tailor measurement of agglomeration impacts to capture either urbanization or localization effects. They are accompanied by a detailed literature review and report on their uses (Texas A&M Transportation Institute, 2013).

Each accessibility tool has a different intended use and ability to capture or reflect localization effects (support for clustering of businesses with similar or complementary activities) and urbanization effects (support for enhanced access to labor, supplier, or customer markets). This comes from their different capabilities regarding zonal system detail, zonal activity measures, decay factors, and threshold factors, as shown in Table 5-2.

These differences lend each tool to a different form of use as follows:

- As a general approach, the effective density tool can be used with zonal employment data to capture the effect of transportation projects on broadening economic markets, reflecting access among firms and employees. This approach, taken in the UK, can represent a composite of business localization and urbanization effects.
- Alternatively, the effective density tool can be used with zonal population as well as employment data to better capture benefits of broader labor and shopper market access (urbanization benefits for industries gaining scale economies from population access).
- The fixed threshold accessibility tool is set up to use zonal employment data for specified industry sectors that have specific clustering characteristics (regarding relevant types of businesses and a proximity or connectivity thresholds) and can best capture localization benefits such as support for clustering and interaction among specific types of businesses (e.g., high-tech clusters or same-day supply chains).

Table 5-2. Market access analysis tools.

Spreadsheet Tool	Zonal Attributes	Decay Factor	Threshold Factor
Effective Density Measurement Tool	Population or Employment	Linear or Exponential, may be Expanded	—
Fixed Threshold Access Tool	Employees by Industry	—	Adjustable Cutoff

The options for zonal metrics, decay and threshold factors are of particular note. The choice of zonal attributes will affect relative rankings of projects. To understand why, consider that most major U.S. cities have office employment more concentrated in central zones while population, housing, and retailing are more dispersed and prevalent in outlying areas. As a result, measuring effective density in terms of zonal employment might show greater gain with improved radial access to the urban center, while measuring effective density in terms of zonal population might show greater gain with a new circumferential (non-radial) suburban corridor project.

Decay and threshold functions can be particularly important for accuracy regarding impacts on business workforce access and supply chain interactions. For instance, same-day parts delivery (needed for just-in-time processes) is limited to legal and practical limits on driver hours/day, while labor market access is limited by acceptable commuting travel times, which tend to attenuate rapidly as travel times go beyond the 40–60 minutes threshold. Further work is needed to understand how decay and threshold functions vary by industry.

5.3.1 Effective Density Access Tool

Overview. This tool was developed by the Texas A&M University Transportation Institute (2013) for SHRP2 Project C11. The tool and its manual are both available for download at www.tpics.us/tools. (It is labeled as "Effective Density: Buyer-Supplier Market Access Tool," though its uses are broader than indicated by that label.)

It is set up to estimate region-based market access impacts (such as changes in effective density) following a transportation improvement in a user-defined case study, and it provides an assessment of the value of the associated productivity gains (or losses) stemming from these access changes. The tool is suited for evaluation of major projects that significantly change the structure of the regional economy, such as network and road system improvements.

Operation. The tool follows the framework for the estimation of agglomeration impacts as featured by Graham (2007) and used by the UK Department for Transport guidance. The model hinges on the use of an exponential decay function to weight the access from a designated zone to all other surrounding zones. From that information, it calculates an economic measure of effective density (a measure of relative market potential) and the sensitivity of productivity to changes in that measure.

The tool is presented as a spreadsheet, which makes it flexible. It looks at comparisons based on two time periods, a base year (no-build) and a do-something reference year (build scenario). The input requirements can be a challenge for users without travel demand models. Nevertheless, the tool can still be used for simplified sketch-level assessments, without the full level of zonal activity detail and interzone impedances typically available from travel demand models.

Modal and Regional Coverage. The tool was designed for assessment of highway projects at a wide regional scale. However, it is defined in sufficiently general terms that it could facilitate different modes with the supporting data. The tool depends on data regarding interzonal impedances (measures of travel time or generalized cost between zones).

Inputs and Outputs. The tool requires the analyst to specify the following:

- *Scope.* Geographic scope (and level of disaggregation) of the activities to be investigated (e.g., employment sectors). The spreadsheet tool can handle a maximum of 40 zones, although it can be expanded further if reprogrammed in a different software package. The zones can be of any geographic scale or level of disaggregation.

- *Travel characteristics.* Associated interzonal travel characteristics, specified as origin-destination matrices that contain interzonal impedance factors representing the time or generalized cost for travel between any pair of zones. This must be completed for both build and no-build scenarios. The guidance outlines the importance of the correct spatial disaggregation and size of study area, and discusses additional issues pertaining to the calculation of intrazonal travel times and appropriate time periods.
- *Zonal activity data.* The system is set up to accept zonal employment as the indicator of industry activity (for shipments and purchases) occurring in each zone. However, it can accept any proxy data representing business activity levels. Alternatively, it could use population data to measure accessibility for home-based commuting, shopping, or other forms of travel. If industry-sector-level data is supplied, the tool can be run separately for different industries, which the documentation recommends if "there is evidence of industry specialization in one or more sectors."
- *Distance decay parameter for density function.* This is known as the α parameter. Although there is some guidance provided on this, it is vague and reflects the fact that this is an under-researched area; it is not much help to the user.
- *Production elasticity parameter.* This requires an understanding of the industry mix of the study area. The documentation glosses over the complexity and importance of finding the appropriate elasticity. Although some ranges for sectors are supplied, these elasticities will widely vary by country, region, agglomeration measure, and productivity measure.

The outputs consist of

- Effective density values for each zone and the total for both scenarios, and
- Monetary value of productivity output in each zone.

Interpretation of Results. This tool is an application of a standard approach to estimating productivity impacts following changes in agglomeration. It measures the value of improved linkages between zones following a transportation improvement. It can be used with zonal data on population, employment, sector-specific employment, or any other zonal descriptor. The interpretation of results will differ depending on the zonal descriptor that is used.

5.3.2 Threshold Market Access Tool

Overview. This tool was developed by the Texas A&M University Transportation Institute (2013) for SHRP2 Project C11. The tool and its manual are both available for download at www.tpics.us/tools. (It is labeled as "Fixed Threshold: Specialized Labor Market Access Tool," although its potential uses are broader than indicated by that label.)

It is designed to calculate how transportation improvements affect access to broader labor markets, which may enable greater matching of worker skills to specialized labor needs, based on change in the effective labor market size accessible from a location. The tool generates a set of market access measures that approximate the value for commuters and employers when transportation projects improve commutes to selected employment centers (business clusters). Specialized labor markets are described as pools of skilled labor that can be grouped by industry, occupation, skill level, age, or other categories. The tool can be used to show how changes to the access of worksites can reduce commuting costs and lead to productivity gains since this enhances the reach of employment centers to labor pools.

Since the tool uses a spreadsheet format, the number of zones is limited to a maximum of 30, a number far less than 500 to 1,500 zones found in some metropolitan transportation models. As a result, the tool can be used directly for small communities, or for aggregated zones in larger regions. It also can be programmed into GIS or other database formats for use of larger zonal systems in major urban areas.

Operation. The tool is presented as a spreadsheet and the general form makes it flexible. It looks at comparisons based on two time periods, a base year (no-build) and a do-something reference year (build scenario). However, the input requirements are onerous, since the labor market assess tool requires detail on the specific labor pool and the overall labor market in each zone. Users need to understand the level of input required and other supporting modeling work needed to generate them.

Modal and Regional Coverage. The tool was designed for assessment of roadway projects within a single urban labor market area (usually a metropolitan or micropolitan area), for which data are available on labor specialization (in terms of occupations or industries).

Inputs and Outputs. The model requires the user to specify a set of zones that comprise the study area. Employment centers are then identified as subsets of these zones. The following information is required:

- Years of analysis for base (no-build) and reference (build) cases;
- Industry sector (e.g., utilities, manufacturing, etc.) for the employment centers;
- Type of labor force (labor force versus employed) and data source (place of work versus place of residence);
- Specialized labor category data (i.e., occupation, industry, age, ethnicity, gender, skill level); and
- Threshold impedance around each employment center (i.e., the typical commute time or distance to the employment centers).

A separate set of parameters is required if the analyst chooses to calculate commuting cost implications. However, these are not needed since they are already covered in the STB analysis. Some of the extra parameters include trip purpose, wage, proportion of wage rate in value of time, time of day, and average speed. Other required inputs include

- Associated transportation networks (specified as origin-destination matrices or "impedance matrices," of cost, as well as time or generalized cost) for the entire study area; and
- Labor force size for the base year and scenario. Each zone of the network requires labor force size information over the zone and within the selected category labor force size information.

The outputs consist of the following:

- *Zone accessibility.* This is the change in the trade area enabled by the transportation improvements. It is presented as the number of zones accessible from the selected worksites before and after the investment (using the input threshold distances).
- *Employment accessibility.* This is a measure of the total employment of the selected category type within a given zone accessible before and after the investment. The concept is that a larger market area will facilitate better job matching and reduced search costs for commuters.
- *Concentration index (CI).* This is a proxy for the strength of agglomeration and an indicator of the business attractiveness of a particular zone. The CI with respect to an employment center in any industry sector (j), zone (k), and commute threshold is given by:

$$CI_{k,threshold} = \frac{E_{j,threshold} / \Sigma_j E_{j,threshold}}{\Sigma_k E_{j,threshold} / \Sigma_k \Sigma_j E_{k,threshold}}$$

Impact on Productivity. This tool provides measures of commuter time savings, employment accessibility and industry concentration. In theory, it can provide information for an external analysis of productivity impacts that draws on relevant elasticities to estimate how a change in accessibility can lead to further change in productivity for specific affected classes of firms. It may be best seen as measuring a specialized subset of the agglomeration impacts that might be captured in the broader effective density calculation tool. If the analyst feels that a particular project's effects are concentrated on enhancing labor market access to businesses

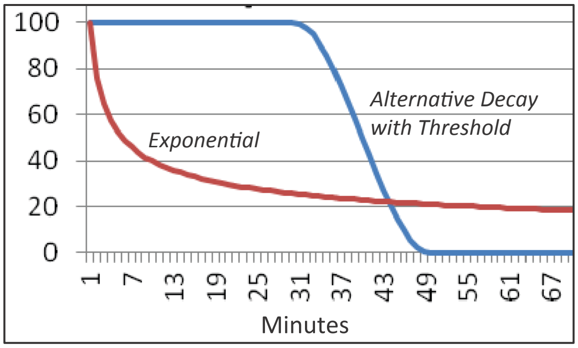


Figure 5-1. Comparison of zonal attraction decay factors.

within a given study area, then this tool can provide a more accurate and detailed specification of that aspect of those agglomeration effects.

5.3.3 Other Variations on Accessibility Measurement

The two tools provide a choice between having an exponential decay in zonal attractiveness that is based on travel time or generalized cost, or having a fixed cutoff for counting zones that fall within a given time or generalized cost threshold. There are also variations on these two ways to measure market access. For instance, Figure 5-1 shows an alternative functional form of decay function for zonal attractiveness that has two notable features: it dampens (or eliminates) the response to small changes in access for easily accessible zones, and it incorporates a threshold effect that zeroes out benefits beyond user-defined limits on interzonal travel times.

The existing spreadsheet tools could be adapted to alternative approaches of this type. That may be appropriate for some situations such as commuting markets, which typically diminish over a 30- to 50-minute range, or same-day delivery markets, which are typically characterized by a 3-hour limit for travel each way, in order to stay within 8-hour periods for round-trip travel with pickup and delivery.

5.4 Intermodal Connectivity Tools

The research team identified one spreadsheet tool that can be used for assessing the connectivity impacts of enhanced access to, from, and through intermodal passenger and freight terminals. Given its limited capabilities and the need for further development of capabilities in this topic area, a brief discussion of the state of intermodal connectivity measurement is provided before the description of the available analysis tool.

Intermodal Measurement Challenges

In theory, intermodal connectivity may be viewed as a specialized extension of local or regional market access benefits. The most fundamental problem is that metropolitan and state transportation network models are typically set up to trace road and transit routes; they are not set up to trace all connecting air, marine, and freight rail routes to external zones. Even if that were attempted, it would become a difficult task to expand to national and international routes and services. Care would be needed to ensure that the process of developing intermodal access metrics and wide-area multimodal networks did not inadvertently affect the accuracy of local travel demand and user benefit calculations.

A more practical, though less precise, alternative form of measurement involves treating airports, marine ports, and rail terminals as special nodes with particular trip generation and attraction properties in surface transportation systems. That approach could allow travel network models to portray improvements in access to these intermodal terminals as having particularly high benefits for freight or business passenger travel, as appropriate. That approach also can reflect the benefits of service and activity expansion at an intermodal terminal, which would increase its trip generation and attraction.

The most straightforward approach, which is utilized with the current tool, uses a gravity model form of decay function to represent the relative attraction of various types of intermodal terminals. Through this function, the relative attraction of an intermodal terminal is defined as a function of the range of destinations served, the frequency of services, and total activity volume at that terminal, while access to it is measured in terms of the relative travel time (or generalized cost) involved in traveling to it. The gravity model formulation reflects the impact of both improving ground access to an intermodal terminal and improving connecting air/sea/rail services offered at that terminal. Those are two very different matters, of course, and the implied tradeoff may not always make sense since firms in an airport-dependent industry would not necessarily find faster travel to an airport to be a substitute for air service to more cities. Yet, it represents the current state of the art in considering intermodal connectivity effects.

5.4.1 Terminal Access Intermodal Connectivity Tool

Overview. The intermodal connectivity access tool was developed by ICF International for SHRP2 Project C-11. The instruction manual (ICF, 2013) and the tool are both available for download at http://tpics.us/tools/.

The intermodal connectivity access tool is a spreadsheet designed to rate the market access for airports, marine ports, and rail terminals in the United States. It works by computing a statistical index that reflects average travel time to access any given intermodal terminal and the magnitude of connecting services to outside origins and destinations that can be accessed from it. The resulting index has no particular meaning itself. By multiplying percent change of the index by an appropriate elasticity factor, the analyst can calculate a percent productivity increase resulting from a change in accessibility to a given intermodal terminal.

Operation. The intermodal connectivity access tool utilizes a database on services provided and levels of use for every intermodal facility in the United States. Users input information about the nature of changes in access to that facility.

The inputs needed to compute the intermodal connectivity index fall into the following classes:

- Scale of activity (person-trips or vehicle-trips) utilizing the intermodal terminal.
- Scale of connecting services provided there, including the frequency of air, marine, or rail services and number of different origins and destinations that can be accessed. This data is preloaded for air and marine terminals within the United States. For assessment of rail terminal connectivity, the user is required to input information on annual container lift capacity.
- Scale of surrounding business activity (employment) that can easily access that terminal and the associated GRP.
- Characteristics of the roadway improvements under consideration—distance of the improvement from the intermodal facility (or fraction of truck trips associated with the facility), and travel time per trip.

The tool provides three outputs:

- Total vehicle-hours saved by enhanced access to a specific intermodal terminal;
- Index of connectivity importance, based on the scale of connecting services provided at the terminal; and
- Product of the preceding two metrics, to portray the magnitude of aggregate time savings, scaled by the importance of the intermodal terminal.

As designed, the tool estimates a weighted connectivity index that can be used to compare the relative value of different roadway investments, each with an associated time savings per vehicle, for connectivity at specific intermodal terminals. With slightly modified inputs, the tool also can be used to assess changes in connectivity, between a base and build case (demonstrated in the case study in Section 5.3). For this type of analysis, the tool must be run twice, once using the base travel time to the terminal, and once with the new reduced travel time. The number of trips using the terminal should not be altered between base and build, as the tool is not set up to assess the impact of induced trip making.

Modal and Regional Coverage. This tool was designed for assessment of changes in road access to transportation nodes that provide transfer to rail, air, and marine transportation modes. It does not distinguish between access to freight terminals and access to passenger terminals. In theory, it could be used for assessing impacts of changes in rail transit access to airports. The spatial scale of analysis is not limited, although the product was designed to capture changes in access to one, two, or three intermodal terminals of the same type that are closest to a given urban area.

Impact on Productivity. The tool provides a connectivity index and does not directly assess impacts on productivity. However, its use for productivity analysis is enabled by focusing on assessing changes in truck access to cargo terminals. An elasticity, such as that presented earlier in Exhibit 2-8, could be used to assess the effect of a given percent change in intermodal accessibility to a resulting change in market scale economies.

It is important to note that there is a strong potential for overlap between the results of this tool and the results of the preceding two tools that rate the effects of expanding the effective size of labor or delivery markets. Connectivity to intermodal terminals is best considered a special case of market access, in which access is affected by the information about the nature of connecting transportation services. For that reason, this tool is recommended for situations where the transportation project is specifically affecting a connector or access road to an intermodal terminal.

5.5 Logistics Cost Analysis Framework

Logistics costs are those associated with the movement of goods along the supply chain from producers to consumers. They include expenses associated with the following six cost elements:

- Freight delivery,
- Materials handling,
- Warehousing and inventory,
- Stockouts (being out of inventory),
- Order processing, and
- Return goods handling.

Transportation investments that enhance the cost, speed, and/or reliability of goods movement can lead to supply chain productivity effects via changes in any of these classes of logistics expense.

While the preceding tools enable the evaluation of productivity benefits associated with direct worker and goods movement costs as well as agglomeration benefits, the same computational methods for assessing broader supply chain effects beyond direct costs of delivery vehicle operating expenses and driver costs are not available. Individual shippers do have their own internal logistics cost models for warehouse and inventory management, but there are no tools readily available for consideration by public agency planning professionals that focus just on logistics costs.

To address this need, the project team developed a four-step framework for assessing the extent of productivity impacts associated with logistics cost reduction. The framework builds on initial research discussed in Brod et al. (2013) and commodity-specific cost analysis demonstrated in Fitzroy et al. (2014). The framework is designed to work through use of a spreadsheet, thus creating a tool that can be used to enable broader productivity impact analysis. Alternatively, the analyst can use a commercial regional economic impact tool such as TREDIS that incorporates similar logistics impact elements in its productivity calculation.

Overview. The framework has the following four steps:

1) Establish the role of logistics cost as part of total cost of delivered products (by industry/commodity and region);
2) Establish how each type of transportation improvement (by mode) affects each element of logistics cost;
3) For any specific transportation improvement in a specific area, calculate the change in travel characteristics and resulting effects on elements of total logistics cost; and
4) Calculate multi-factor productivity impacts from the direct savings in logistics costs.

Step 1: Establish the Role of Logistics in the Total Cost of Delivered Products

The impact of transportation system changes on logistics processes depends on the volume and mix of affected freight movements. Some goods have significantly greater inventory and stock carrying requirements (and costs) than others. The transportation and logistics costs associated with any given commodity movements will depend on the weight and delivery timing requirements of those commodities, and the resulting modes used.

To identify the affected industries, it is first necessary to obtain a profile of the volume of freight vehicle movements that are affected by the project, and the mix of commodities and associated tonnages that are affected. This information may be obtained from several possible sources: a survey of area businesses (shippers), estimated from a state freight model, estimated by consultant studies, or obtained from commercial sources such as the TranSearch database of IHS Global Insight or the TREDIS freight tool. Regional economic models such as REMI TranSight and TREDIS also can derive rough estimates of the affected mix of freight commodity movements based on the economic profile of the study area.

To estimate the magnitude of logistics costs associated those freight movements, it is possible to rely on the Transportation Satellite Accounts (TSA). This is a special add-on to the U.S. input-output tables that accounts for business use of in-house vehicle fleets (owned and operated by manufacturers, retailers, and other non-transportation businesses), in addition to use of for-hire transportation, warehousing, and wholesale distribution services for each industry. Table 5-3 shows a summary breakdown of those costs by industry; detail by mode and by commodity is available at www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/transportation_satellite_accounts/2011/index.html.

Note that the use of percentages can be misleading, as high-value goods tend to have greater transportation and inventory costs than other goods, but those costs appear as a lower percentage of product value. Ratios of average value per ton are available by commodity from the FAF at www.ops.fhwa.dot.gov/freight/freight_analysis/faf.

Table 5-3. Transportation and inventory cost factors, by industry (based on U.S. Transportation Satellite Accounts).

Commodity/Industry	Transportation Cost: For Hire + in-House Cost (%)	Manufacturing & Wholesale: Inventory & Warehouse (%)	Total as % of Product Value
Crop products	9.8	4.5	14.3
Animal products	8.5	4.5	13.0
Forestry and logging products	16.1	1.6	17.7
Fish and other nonfarm animals	7.0	3.2	10.2
Coal	23.3	2.4	25.7
Metal ores	10.5	2.7	13.2
Non-metallic minerals	11.9	2.4	14.3
Food products	4.7	6.1	10.8
Beverage products	4.5	6.9	11.4
Yarn, fabrics, other mill products	3.7	5.0	8.7
Apparel	1.9	5.5	7.4
Wood products	6.0	6.6	12.6
Paper, and paper board	4.8	5.9	10.7
Printed products	4.7	5.8	10.5
Petroleum and coal products	5.8	5.2	11.0
Basic chemicals	3.3	6.0	9.3
Resins, rubber, and artificial fibers	3.6	5.3	8.9
Agricultural chemicals	8.3	5.4	13.7
Pharmaceuticals and medicines	1.3	5.7	7.0
Paints, coatings, and adhesives	4.6	5.2	9.8
Soaps, cleaning, and toiletries	2.3	6.0	8.3
Other chemical products	4.4	7.2	11.6
Plastics and rubber products	5.0	4.6	9.6
Non-metallic mineral products	11.8	3.3	15.1
Primary ferrous metal products	6.7	8.6	15.3
Primary non-ferrous metal products	5.0	7.0	12.0
Foundry products	4.1	5.2	9.3
Forgings and stampings	3.0	5.5	8.5
Boilers, tanks, shipping containers	2.9	6.3	9.2
Industrial machinery	1.7	6.1	7.8
Commercial industry machinery	1.8	7.6	9.4
HVAC and refrigeration equipment	2.0	7.7	9.7
Metalworking machinery	1.8	4.0	5.8
Turbine and power equipment	2.6	4.8	7.4
Computer & peripheral equipment	0.9	14.4	15.3
Audio, video & comm. equipment	1.0	5.9	6.9
Semiconductors, elect components	1.0	5.3	6.3
Electronic instruments	1.2	5.3	6.5
Magnetic media products	2.3	3.1	5.4
Household appliances	2.4	7.3	9.7
Electrical equipment	1.8	8.9	10.7
Motor vehicles	2.7	5.3	8.0
Aerospace products and parts	2.5	3.8	6.3
Other transportation equipment	2.9	5.0	7.9
Furniture and related products	4.7	6.1	10.8
Medical equipment and supplies	3.4	5.2	8.6
Waste management services	18.5	2.0	20.5

The TSA data is incomplete as a measure of total supply chain costs because it does not break out other elements including administration, labor, customer service, rent, or the cost of capital tied up in inventory. To utilize information on these additional costs, it is necessary to access private data, as discussed in McKinnon (2003) and Rodrigue (2013).

In the long run, all of those factors can be affected by transportation reliability and efficiency changes. However, in the near term, the most critical factors affected by transportation speed and reliability changes are cargo delivery cost and inventory (warehouse and wholesale stocking) cost. Ideally, the analysis should rely on regional, rather than national, data for those costs, since the selection of transportation modes and level of inventory required may vary across regions depending on shipment distances, frequency, and travel time variability.

Step 2: Determine How Transportation Projects will Affect Logistics Elements

Transportation investment projects affect logistics costs by changing the way that freight vehicles and supporting workers are utilized. For instance, a survey (McKinnon, 2003) of delivery truck time over the course of a typical workday has been reported to be as follows: idle (28 percent), maintenance/repair (7 percent), waiting for loading/unloading (4 percent), waiting for departure (15 percent), loading and unloading (16 percent), on the road (28 percent). Each type of transportation improvement can affect a different aspect of these activities.

1. By enabling faster travel times, the labor time cost of deliveries falls. This element is already captured in STBs (discussed in Section 3.4).
2. By enabling more direct routes, the operating cost of vehicles may be reduced. This element is also captured in STBs (discussed in Section 3.4).
3. By enhancing travel time reliability, three logistics benefits may occur: inventory stocking requirements and associated costs may be reduced, worker idle time may be reduced, and overtime pay for loading dock workers may be reduced.
4. By expanding vehicle cargo capacity (in terms of bridge loads, runway lengths and loads, marine port depth, or truck size and weight limits), asset utilization may be enhanced by enabling larger loads per vehicle, fewer vehicle-trips, and greater output per worker.
5. In the long run, delivery times that are consistently and reliably shorter can enable reorganization of distribution systems, with more centralized inventory now possible. That can lead to scale economies with a reduction in the amount of inventory value that is tied up because it is either at the warehouse or on vehicles (in transit). It can also lead to further downstream productivity benefits associated with lean supply chains and more integrated just-in-time production processes.

Thus, transportation projects can influence productivity via a process in which transportation system changes (measured as VMT, VHT, buffer time, and vehicle loads) lead to changes in logistics process costs (measured as changes in driver, loading dock, and warehouse labor hours, vehicle costs, and inventory carrying costs). Since the driver and vehicle costs (preceding Categories 1 and 2) are captured in STB analysis, the remainder of the steps focus on non-driver labor and inventory costs (Categories 3, 4, and 5) which lead to productivity impacts that are not otherwise measured elsewhere.

Step 3: Translate Transportation Changes into Logistics-Related Cost Elements

The effect of transportation projects on improving cargo pickup and delivery reliability can be directly translated into logistics cost impacts. The buffer time measure is most applicable as an indicator of the additional time that businesses build into freight pickup and delivery schedules to maintain 95 percent on-time reliability.

NCHRP Report 755 (Brod et al., 2013) provides discussion and a calculation framework for considering the inventory cost of delay:

> The carrying cost of in-transit inventory is the time value of goods tied up while they are in transit. Delaying a delivery imposes what economists call an opportunity cost of capital, which represents the foregone return on investment during the period of added time on vehicle, which occurs whether shipments are unexpectedly delayed or just subject to schedule padding (slack) that is introduced to allow for the possibility of delay. There are further costs associated with an unexpected late delivery (e.g., overtime pay for loading dock workers or just-in-time penalties) or a missed delivery window (e.g., costs of redelivery).

Factors affecting logistics costs are shown in Table 5-4.

Delay costs are shown per ton-hour, although average vehicle loadings are also shown so that inventory delay costs can be converted to a cost per vehicle-hour. Of course, some truck, rail car, and container movements are just empty backhauls. For planning studies, it may be easier to do the calculations in terms of tonnage because profiles and forecasts of freight tonnage flows are readily available from the U.S.DOT's FAF and Commodity Flow Survey, while data on container loadings is far less broadly available.

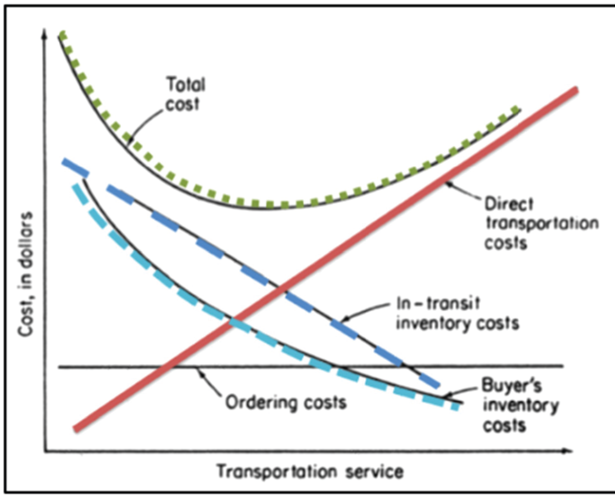
The direct cost saving benefits of increased reliability can go far beyond just savings in the cost of capital that is tied up. There also can be added transportation expenses, administrative expenses, and warehouse operating expenses. In the long run, much more substantial cost savings may be obtained as greater reliability enables warehouse centralization and consolidation. Those opportunities and benefits of warehouse centralization will depend on the specific regional context. As noted in *NCHRP Report 755* (Brod et al., 2013) and illustrated in the following Figure 5-2:

> The basic tradeoff is between the two broad cost components of transportation and inventory. In the figure below, those costs are plotted against shipment size and number of warehouses. In the short run, crashes cause transportation costs to increase (e.g., tied-up capital, expedited shipping costs, penalties, handling costs).
>
> [If reliability degrades over the long run,] more warehouses (stocking points) will be needed. Adding warehouses/stocking points causes average inventory levels to rise to maintain or meet a given level of customer service. This occurs because of the need for increased inventory by downstream buyers and from adding safety stock in shipper warehouses to hedge against future loss and delivery reliability risks.

Table 5-4. Logistics cost factors associated with delivery reliability.

<table>
<tr><th>Factor</th><th>Type of Freight</th><th>Commercial Truck</th><th>Freight Rail</th></tr>
<tr><td rowspan="3">Inventory Carrying Cost
(Time Cost of Capital) per Ton-Hour of Delay</td><td>Bulk commodities</td><td>$0.05</td><td>$0.02</td></tr>
<tr><td>Manufactured goods</td><td>$0.36</td><td>$0.21</td></tr>
<tr><td>Composite average</td><td>$0.09</td><td>$0.02</td></tr>
<tr><td rowspan="2">Average Capacity (Tons per Vehicle)</td><td>Bulk commodities</td><td>10.0</td><td>7,430</td></tr>
<tr><td>Manufactured goods</td><td>17.5</td><td>3,024</td></tr>
<tr><td rowspan="3">Excess Labor Cost (Wage per Worker-Hour)</td><td>Truck/train crew</td><td>$19.88</td><td>$26.40</td></tr>
<tr><td>Warehouse (sched. time)</td><td colspan="2">$14.77</td></tr>
<tr><td>Warehouse (overtime)</td><td colspan="2">$22.15</td></tr>
</table>

Source: This table is updated from *NCHRP Report 755* (Brod et al., 2013) (original report showed cost per vehicle-hour rather than ton-hour) and wage rates have been updated. Cost of Capital is based on value of cargo, from FAF; Truck Loading is from the U.S.DOT Comprehensive Truck Size and Weight Study; Rail Loading is from AAR Class I Railroad Statistics; Labor Cost is from the BLS National Compensation Survey, overtime is assumed to be time and a half.



Total Logistics Cost is a function of transportation costs and inventory costs. This can be written as:

TLC (Q,r: T,ST) = RD_i + ($UCTD_i$/365) + (SD_i/Q) + QCI/2) + rIC + K(D_i/Q) N(Z)*S1* where:

TLC = Total Logistics Cost
Q = Order Quantity
R = Rate of Transport Cost (Origin to Destination)
D_i = Annual Demand for some good "i"
U = Carrying Cost of In-transit Inventory
C = Value per Unit
T = Transit Time of Transportation Alternative
S = Fixed Ordering Cost per Order
I = Carrying Cost of Warehoused Inventory
r = Safety Stock
K = Stockout Cost per Unit
N(Z) = Unit Loss Integral
ST = Std. Deviation of Demand during Lead Time
S1 = Std. Deviation of Demand during Transit Time

Source: Graph from HLB Decision Economics, 2008); formula from Chow (2010)

Figure 5-2. Total logistics cost and transport—warehousing cost tradeoffs.

Step 4: Translating Logistics Costs to Productivity Effects

The thread of the argument has been that transportation changes can and do lead to changes in logistics costs along the supply chain, and these cost reductions lead to incremental gains in efficiency over time as firms fully adjust inventory and distribution practices. Formally, $(T \times L_j)$ is the change in logistics cost due to a transportation investment T and L_j is the j component of logistics cost L. To calculate the productivity change, we multiply by $(T \times L_j \times \phi_j)$ where ϕ_j is a factor that translates logistics cost change into productivity change.

The aggregate change in productivity is

$$\Delta Pr = \sum_k \sum_j T_k L_j \theta_j \qquad (1)$$

and the change in GDP is

$$\Delta GDP = \Delta Pr \cdot GDP \qquad (2)$$

Rasamit (2003) estimated regression models covering a 15-year period to estimate the relationship between total factor productivity (TFP, which is the same as multi-factor productivity) and various elements of logistics cost, inventory level, inventory carrying rate, and inventory carrying costs. The resulting regression coefficients are shown in Table 5-5. Since the dataset is not current, actual factors may need further updating. Nevertheless, they provide a means for assessing the potential magnitude of impacts that a transportation project can have on supply chain costs.

The regression results show a negative relationship between logistics cost and productivity, meaning that productivity rises as logistics costs fall. They also show that these changes evolve over time, with productivity changes after 1 year more pronounced than immediate changes, a phenomenon that diminishes by the second year as further business adjustments take place.

It is important to note that these impacts, like many other effects considered in this report, appear as small percentage changes. However, when these small percentage changes are applied to an entire regional economy (or a sector of that economy), the end results can be very significant in absolute terms.

Table 5-5. Relation between logistics cost factors and TFP.

Logistics Variables	Models Examined		
	No Time Lag	1-Year Time Lag	2-Year Time Lag
Logistics Cost	-0.003	-0.011	-0.004
Inventory Level	-0.009	-0.009	-0.003
Inventory Carrying Rate	-0.0003	-0.009	-0.006
Inventory Carrying Costs	-0.006	-0.018	-0.005
Transportation Costs	-0.009	-0.004	-0.006

Source: Rasamit (2003)

Use of these coefficients is illustrated by the following examples:

- An 11 percent reduction in inventory levels—Applying a coefficient of –0.009, the resulting value for $(T \times L_j)$ is an increase in productivity of 0.00099.
- A 6 percent reduction in fleet and warehouse carrying costs—Applying a coefficient factor of –0.006, the resulting value for $(T \times L_j)$ is an increase in productivity of 0.00036.
- The savings in total factor productivity is 0.00135 times the value added of the affected industry in the affected region (i.e., an 0.135 percent increase). Assuming that regional industry had an annual value added of $15 billion per year, then the productivity gain would be $20M per year.

5.6 LUTI and Macroeconomic Impact Analysis Tools

5.6.1 Land-Use Transportation Integration (LUTI) Models

LUTI models are currently operational in only a limited number of state DOTs and MPOs in America, but when available they can provide important insights into the relationship between productivity benefits and changes in market access. LUTI models also can contribute to agglomeration calculations, by forecasting impacts of transportation investments on employment location patterns.

Accessibility to markets is an important common consideration in both benefit-cost analysis (BCA) and LUTI models—as an add-on to conventional BCA calculations, and as a set of important intermediate factors in LUTI modeling. In many LUTI models, measures of access to markets of different kinds are the key variables through which transportation influences land use and the economy. Accessibility calculations combine large quantities of land-use data (about the spatial distribution of the "market" being considered) and transportation data (usually in the form of generalized costs of interzonal travel). This information is used to derive summary measures of the relative attractiveness of each zone as a location in which to produce various goods and services, which need to be delivered to a set of consumers, or to consume various goods and services, which need to be provided by a set of suppliers (in the case of the labor market, this means households).

LUTI models also come into consideration as one way to incorporate market access benefits and their productivity effects in BCA. Traditional user benefit assessment, using a standard transportation network model, effectively assumes that land-use patterns evolve over time in a similar fashion regardless of whether the base case or alternative case scenarios take place. (That assumption is a basis for applying the "rule of one-half" to calculate consumer surplus from changes in VMT, VHT, and trips.) That assumption does not hold when there are changes in trip rates and trip patterns caused by land-use changes between the base and the alternative cases, or market access economies—forecast by a LUTI model.

This has led to debate about the practicability of enhancing standard BCA to account for access impacts (as well as intermodal connectivity impacts), or otherwise devising a new land-use-based BCA. This type of approach could recognize the consumer surplus value for residents resulting from improving the accessibility of zones to relevant markets, rather than focusing just on the calculation of generalized cost savings for specific trips (Simmonds, 2012). Further work is needed to develop equivalent calculations for businesses. The approach appears to be applicable with any LUTI model, but this would need to be tested using real results from a range of models.

A constraint associated with the current generation of LUTI models used in the United States is that they generally reallocate economic activity on the basis of accessibility changes, but maintain a "control total" for overall regional economic growth. That process works to limit apparent productivity impacts, because it is increased trade with the rest of the country and world (via increases in product exports and inward investment) that actually enables productivity to grow at a regional level. Regional macroeconomic impact models can come into play for addressing this issue. (For instance, the Ohio statewide model is attempting to address this issue through the addition of broader macroeconomic responses.)

5.6.2 Regional Macroeconomic Models

As discussed earlier in this report (Section 1.4), multi-factor productivity is a macroeconomic concept, and its full implications can only be understood through use of regional macroeconomic models that forecast how direct effects on the elements of business productivity can lead to broader changes over time in relative costs and flows of labor, investment, and trade. To varying degrees, all of the major regional economic impact modeling systems can help to measure those effects.

In general, these models take input information regarding project impacts on travel time, cost, reliability, and market access, and calculate expected future impacts on growth of productivity, job creation, income, and GDP. They do so by simulating effects on business operating costs, supplier and customer markets, demand and supply of labor, and flows of goods and services between regions, as well as household migration and spending patterns.

Since economic impact forecasting models rely on detailed information about local and regional economies, as well as forecasts of how their economies will evolve over time, they generally require datasets and software systems to be obtained from universities or private firms. Such models are available for U.S. states and counties, as well as Canadian provinces, as licensed products available via lease or subscription. The dominant tools in North America—REMI TranSight, TREDIS, and INFORUM—have all been used to assess productivity impacts of transportation investment.

The first two incorporate elements of Krugman's new economic geography, building on works by Weisbrod and Treyz (1998, 2001) that related market access to productivity. REMI TranSight uses a concept of effective distance to portray market access impacts, while TREDIS uses a concept of effective market size to calculate scale effects. Both can address logistics effects, though they differ in their freight modal detail. Both are currently limited to multi-regional impacts within a national control forecast, though the latter has been used together with the INFORUM-LIFT international trade model to show how transportation investment policies can ultimately influence productivity and economic growth at a national level.

In all of these cases, the usefulness of macroeconomic impact calculations will depend on the quality of transportation impact forecasts that comprise their inputs. In the context of this research, the regional economic impact models are of particular note because they portray the mix of industries and the inter-regional trade flows that would be affected by (and gain productivity from) proposed transportation improvements.

References

For a complete bibliography, please refer to NCHRP Project 02-24: Literature Review and Stakeholder Perspectives at http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP02-24_Task1LitReview.pdf.

Alstadt, B., G. Weisbrod, and D. Cutler (2012). "Relationship of Transportation Access and Connectivity to Local Economic Outcomes: Statistical Analysis," *Transportation Research Record: Journal of the Transportation Research Board*, No. 2297, 154–163, http://trb.metapress.com/content/r575w50h31n06563/

American Automobile Association (2012). *Your Driving Costs.* Heathrow, FL, http://newsroom.aaa.com/wp-content/uploads/2012/04/YourDrivingCosts2012.pdf

American Transportation Research Institute (2013). *An Analysis of the Operational Costs of Trucking: 2013 Update*, http://www.atri-online.org

Aschauer, D. A. (1989). "Is Public Expenditure Productive?" *Journal of Monetary Economics*, 23, 177–200.

Asensio, J. and A. Matas (2008). "Commuters' Valuation of Travel Time Variability," *Transportation Research Part E: Logistics and Transportation Review*, Elsevier, Vol. 44, Issue 6, November, 1074–1085.

Börjesson, M. and J. Eliasson (2008). "Train Passengers' Valuation of Travel Time Unreliability," *Proceedings of the European Transport Conference*, Leiden, Netherlands, October.

Brod, D., G. Weisbrod, C. Williges, S. Moses, D. Gillen, and C. Martland (2013), *NCHRP Report 755: Comprehensive Costs of Highway-Rail Grade Crossing Crashes*, Transportation Research Board, http://www.trb.org/Main/Blurbs/169061.aspx

Brownstone, D. and K. A. Small (2005). "Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstrations," *Transportation Research Part A: Policy and Practice*, Vol. 39, 2005, 279–293.

Cambridge Systematics et al. (2013a). *Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*, SHRP2 Report S2-L03-RR-1, Transportation Research Board, Washington, D.C., http://www.camsys.com/pubs/SHRP2_S2-L03-RR-1.pdf

Cambridge Systematics and Weris (2013b). "Reliability Analysis Tool: Technical Documentation and User's Guide," Ch. 3 in Economic Development Research Group, et al., *SHRP2 Project C11: Development of Tools for Assessing Wider Economic Benefits of Transportation*, http://www.tpics.us/tools/documents/SHRP-C11-Reliability-Tech-Doc-and-User-Guide.pdf

Carrion, C. and D. Levinson (2010). "Value of Reliability: High Occupancy Toll Lanes, General Purpose Lanes, and Arterials," *Conference Proceedings of 4th International Symposium on Transportation Network Reliability in Minneapolis, MN.*

Chow, G. (2010). A Total Logistics Cost Approach to Measuring Collateral Benefits of Security and Supply Chain Improvements at International Gateways, paper presented at Asia Pacific Gateway and Corridor Conference, Vancouver, http://www.gateway-corridor.com/roundconfpapers/documents/Chow_Garland_Calgary.pdf

Ciccone, A. (2002). "Agglomeration Effects in Europe," *European Economic Review*, Vol. 46, Issue 2, February, 213–227.

Ciccone, A. and R. E. Hall (1996). "Productivity and the Density of Economic Activity," *American Economic Review*, American Economic Association, Vol. 86, No. 1, March, 54–70.

De Jong, G. et al. (2009). "Preliminary Monetary Values for the Reliability of Travel Times in Freight Transport," *European Journal of Transport and Infrastructure Research*, Vol. 9, Issue 2, June, 83–99.

Delcan Corporation (2014). *Incorporating Reliability Performance Measures in Operations and Planning Modeling Tools*, SHRP2 Project L04 Report, National Academy Press, Washington, D.C., http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2193

Economic Development Research Group, et al. (2012). *NCHRP Project 02-24: Literature Review and Stakeholder Perspectives*, Transportation Research Board, Washington, D.C., http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP02-24_Task1LitReview.pdf

Economic Development Research Group, Cambridge Systematics, ICF International, Texas Transportation Institute, and Weris (2013). *SHRP2 Project C11: Development of Tools for Assessing Wider Economic Benefits of Transportation*, Transportation Research Board, Washington, D.C., http://www.trb.org/Main/Blurbs/169524.aspx

Eddington, R. (2006). *The Eddington Transport Study—The Case for Action: Sir Rod Eddington's Advice to Government.* Controller of Her Majesty's Stationery Office and Department for Transport, Norwich, England, http://webarchive.nationalarchives.gov.uk/20090104005813/http:/www.dft.gov.uk/about/strategy/transportstrategy/eddingtonstudy/

Ellison, G., E. L. Glaeser, and W. Kerr (2007). "What Causes Industry Agglomeration? Evidence from Coagglomeration Patterns." Harvard Business School, paper 07-064, www.hbs.edu/faculty/Publication Files/07-064.pdf

Fitzroy, S., B. Alstadt, and D. Cutler (2014). "New Methods for Assessing the Costs of Delay and Reliability on Major Highway Corridors: A Commodity-Focused/Industry Sector Approach for Addressing Freight Planning," *Proceedings of the International Transportation and Economic Development Conference*, http://www.edrgroup.com/pdf/Fitzroy-ITED-2014.pdf

Fosgerau et al. (2008). *Travel Time Variability Definition and Valuation.* Technical University of Denmark, Transport Department, Lyngby, Denmark, August.

Ghosh, A. (2001). "Valuing Time and Reliability: Commuters' Mode Choice from a Real Time Congestion Pricing Experiment," doctoral diss, University of California at Irvine, Irvine, CA, http://www.uctc.net/research/diss053.pdf

Graham, D. (2007). "Agglomeration, Productivity and Transport Investment," *Journal of Transport Economics and Policy*, Vol. 41, Part 3, September, 317–343, www.internationaltransportforum.org/jtrc/DiscussionPapers/DiscussionPaper11.pdf

Graham, D. J., S. Gibbons, and R. Martin (2009). *Transport Investment and the Distance Decay of Agglomeration Benefits*, Imperial College London, UK Department for Transport, http://personal.lse.ac.uk/gibbons/Papers/Agglomeration%20and%20Distance%20Decay%20Jan%202009.pdf

HLB Decision Economics and ICF International (2008). Freight Benefit/Cost Study: Phase III - Analysis of Regional Benefits of Highway-Freight Improvements, FHWA Freight Office, U.S.DOT. http://ops.fhwa.dot.gov/freight/freight_analysis/econ_methods/freight_cba_study/index.htm

ICF International (2013). "Connectivity Analysis Tool: Technical Documentation and User's Guide," Ch. 4 in Economic Development Research Group, et al., *SHRP2 Project C11: Development of Tools for Assessing Wider Economic Benefits of Transportation*, http://www.tpics.us/tools/documents/SHRP-C11-Connectivity-Tech-Doc-and-User-Guide.pdf

Jiwattanakulpaisarn, P., R. B. Noland, and D. J. Graham (2012). "Marginal Productivity of Expanding Highway Capacity," *Journal of Transport Economics and Policy*, Vol. 46, Part 3, September, 333–347.

Krugman, P. (1998). "Role of Geography in Development," *Proceedings of the World Bank Annual Conference on Development Economics*, World Bank, Washington, D.C., http://www.signallake.com/innovation/Geography KrugmanApr98.pdf

Laird, James (2006). Commuting Costs and their Impact on Wage Rates, Institute of Transport Studies, University of Leeds, Working Paper 587, http://eprints.whiterose.ac.uk/2056/1/ITS31_WP587_uploadable.pdf

Li, Z., D. A. Hensher, and J. M. Rose (2010). "Willingness to Pay for Travel Time Reliability in Passenger Transport: A Review and Some New Empirical Evidence," *Transportation Research Part E: Logistics and Transportation Review*, Vol. 46, Issue 3, May, 384–403.

Lucas, Robert E., Jr. and Esteban Rossi-Hansberg (2002). "On the Internal Structure of Cities," *Econometrica*, Vol. 7, No. 4, 1445–1476.

Mamuneas, T. P. and M. I. Nadiri (2006). *Production, Consumption and the Rates of Return to Highway Infrastructure Capital.* Prepared for the Federal Highway Administration, https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=IIPF62&paper_id=11

McKinnon, Alan (2003). *The Effects of Transportation Investments on Logistics Costs*, ESRC Seminar Series, Program in Transport Investment and the Economy, Oxford University, www.sml.hw.ac.uk/downloads/logisticsresearchcentre/congestion-reliability/McKinnon-TSUOxford.pdf

McMillen, Daniel P. and Larry D. Singell (1992). "Work Location, Residence Location, and the Intraurban Wage Gradient." *Journal of Urban Economics*, Vol. 32, No. 2., 195–213.

Melo, Patricia, Daniel Graham, and Ruben Brage-Ardao (2013). "The Productivity of Transport Infrastructure Investment: A Meta Analysis of Empirical Evidence," *Regional Science and Urban Economics*, Vol. 43, 695–706.

Melo, P., D. Graham, and R. Noland (2009). "A Meta-Analysis of Estimates of Urban Agglomeration Elasticities," *Regional Science and Urban Economics*, Vol. 39, Issue 3, May, 332–342.

Mills, Edwin S. (1967). "An Aggregative Model of Resource Allocation in a Metropolitan Area," *American Economic Review*, Vol. 55, No. 2, 197–210.

Oak Ridge National Laboratory (2009). National Household Travel Survey, http://nhts.ornl.gov/tables09/FatCat.aspx?action=excel&id=3

Ogawa, Hideaki and Masahisa Fujita (1980). "Equilibrium Land Use Patterns in a Nonmonocentric City," *Journal of Regional Science*, Vol. 20, No. 4, 455–475.

Organisation for Economic Cooperation and Development (2001). *Measuring Productivity: OECD Manual*, www.oecd.org/std/productivity-stats/2352458.pdf

Rasamit, Thanattaporn (2003). "The Aggregate of Logistics Cost and Total Factor Productivity," MSc thesis, MIT, Cambridge, MA, http://dspace.mit.edu/bitstream/handle/1721.1/28576/57468268.pdf?sequence=1

Rodrigue, Jean-Paul (2013). *The Geography of Transport Systems*, 3rd ed, New York: Routledge, ISBN 978-0-415-82254-1.

Rosenthal, S. S. and W. C. Strange (2003). "Geography, Industrial Organization, and Agglomeration," *Review of Economics and Statistics*, MIT Press, Vol. 85, Issue 2, May, 377–393.

Simmonds, D. C. (2012). "Developing Land-Use/Transport Economic Efficiency Appraisal." Paper presented to the European Transport Conference, Glasgow, 8–10 October, www.davidsimmonds.com/files/LUTEE-paper-for-ETC-v3-111012-1.pdf

Small, K. A., C. Winston and J. Yan (2005). "Uncovering the Distribution of Motorists' Preferences for Travel Time and Reliability," *Econometrica*, Vol. 73, Issue 4, July, 1367–1382.

Texas A&M Transportation Institute (2013). "Accessibility Analysis Tool: Technical Documentation and User's Guide," Ch. 5 in Economic Development Research Group, et al., *SHRP2 Project C11: Development of Tools for Assessing Wider Economic Benefits of Transportation*, www.tpics.us/tools/documents/SHRP-C11-Accessibility-Tech-Doc-and-User-Guide.pdf

Timothy, Darren and William C. Wheaton (2001). "Intra-Urban Wage Variation, Employment Location, and Commuting Times," *Journal of Urban Economics*, Vol. 50, 338–366.

U.S. Bureau of Economic Analysis (2013). Regional Economic Accounts, http://bea.gov/regional/index.htm

U.S. Congress (2012). Moving Ahead for Progress in the 21st Century Act, HR 4348, Section 1115, National Freight Policy, Section (b)(1)(C), U.S. Govt. Printing Office, http://www.gpo.gov/fdsys/pkg/BILLS-112hr4348enr/html/BILLS-112hr4348enr.htm

U.S.DOT (2011). "Interim Notice of Funding Availability for the Department of Transportation's National Infrastructure Investments Under the Full-Year Continuing Appropriations," *Federal Register*, Vol. 76, No. 127, July 1, 2011, 38719–38740, www.dot.gov/sites/dot.dev/files/docs/vot_guidance_092811c.pdf

U.S.DOT (2012). *TIGER Grant Program: Benefit-Cost Analysis Resource Guide*, www.dot.gov/sites/dot.dev/files/docs/tiger-12_bca-resourceGuide.pdf

Van Ommeren, Jos and Piet Rietveld (2005). "Compensation for Commuting in Imperfect Urban Markets," *Papers in Regional Science*, Vol. 86, No. 2, June.

Venables, A. J. (2007). "Evaluating Urban Transport Improvements: Cost–Benefit Analysis in the Presence of Agglomeration and Income Taxation," *Journal of Transport Economics and Policy*, Vol. 41, No. 2, 173–188.

Weisbrod, G. and F. Treyz (1998). Productivity and Accessibility: Bridging Project Specific and Macroeconomic Analyses of Transportation Investments, *Journal of Transportation and Statistics*, Vol. 1 No. 3, http://ntl.bts.gov/lib/9000/9100/9102/5weis.pdf

Weisbrod, G., D. Vary, and G. Treyz (2001). *NCHRP Report 463: Economic Implications of Congestion*, Transportation Research Board, Washington, D.C., http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_463-a.pdf and http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_463-b.pdf

Wheaton, William (1977). "A Bid Rent Approach to Urban Housing Demand," *Journal of Urban Economics*, Vol. 4, 200–217.

Wheaton, William (2004). "Commuting, Congestion, and Employment Dispersal in Cities with Mixed Land Use," *Journal of Urban Economics*, Vol. 55, 417–438.

White, Michelle J. (1988). "Location Choice and Commuting Behavior in Cities with Decentralized Employment," *Journal of Urban Economics*, Vol. 25, 129–152.

Wu, Claudia (2005). "Total Supply Chain Cost Model," MBA and Masters of Engineering thesis, MIT, Cambridge, MA, http://dspace.mit.edu/handle/1721.1/34869

Yan, J. (2002). "Heterogeneity in Motorists' Preferences for Time Travel and Time Reliability," University of California Transportation Center, Working Paper No. qt7nk0v3kj, January, http://escholarship.org/uc/item/7nk0v3kj.pdf

Zax, Jeffrey S. (1991). "Compensation for Commutes in Labor and Housing Markets," *Journal of Urban Economics*, Vol. 30, No. 2, 192–207.

Zheng, Siqi, Richard B. Peiser, and Wenzhong Zhang (2009). "The Rise of External Economies in Beijing: Evidence from Intra-Urban Wage Variation," *Regional Science and Urban Economics*, Vol. 39, 449–459.

APPENDIX A

Further Refinements

A1. Measurement of Travel Time Variability

Travel times may vary for different reasons, including road construction, scheduled special events, crashes, disabled vehicles, and weather conditions. In this report, the focus has been exclusively on non-recurring congestion related to high volume/capacity ratios that cause increasingly long queues and delays to occur from what would otherwise be minor incidents. There are many ways to measure the road delays that can occur under these conditions. They include standard statistical measures (e.g., standard deviation, percentile-based measures such as 95th percentile travel time, buffer time), on-time measures (e.g., percent of trips completed within a travel time threshold), and failure measures (e.g., percent of trips that exceed a travel time threshold).

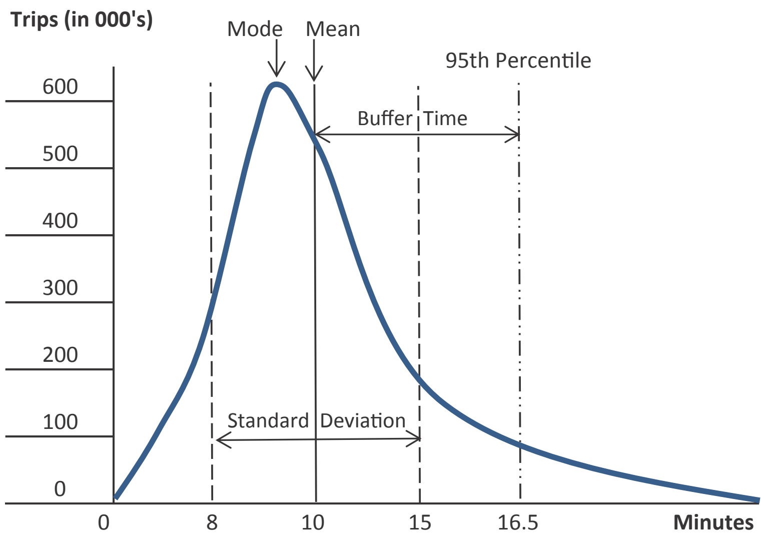
Although all of these metrics can be reasonable for statistical analysis, there are special considerations when the goal is to assess productivity effects. To understand why, the distribution of travel time shown in Figure A-1 and the two scenarios that follow are presented.

Consider a scenario of uncongested (unconstrained) road conditions, in which case the travel time on a given road link will have a normal, bell-shaped distribution around the mean. The breadth of actual travel times will sometimes be less and sometimes be greater than the mean, due to random aspects of weather or demand factors. The degree of variation or dispersion around the mean, measured in terms of the standard deviation of travel times, will have no particular relationship with the mean value.

Now consider a scenario of increasingly congested conditions, in which case the distribution of travel times stretches out to the right of the mean as shown in Figure A-1. In other words, as traffic congestion grows, both the frequency and severity of traffic backups triggered by otherwise minor incidents will grow. The incidence of delays causing longer travel times grows, while there is no change in the incidence of shorter travel times. Thus, the distribution becomes skewed. With this second scenario, the mean and standard deviation are also no longer independent, for as congestion continues to grow and the travel time distribution becomes increasingly skewed to the right side (longer travel times), the mean is also pulled in that same direction.

Relevance for Productivity Impact Measurement

From the viewpoint of business productivity calculation, it is the right side of distribution (longer-than-expected travel times) that affects business costs. This occurs insofar as occasions of longer-than-expected travel time leads to late worker arrivals, late deliveries, a reduction in the number or breadth of deliveries that can be made within a given workday, and increased requirements for worker overtime and inventory "safety stocks." On the other hand, there are typically no systematic business productivity gains associated with occasions of early arrivals of workers and truck deliveries.



Source: Economic Development Research Group et al., (2013)

Figure A-1. Illustration of travel time variability and associated metrics.

These considerations make a strong case that a two-tailed measure of standard deviation is a poor measure to use for calculating the business productivity effects of travel time reliability changes. At a minimum, it is desirable to distinguish the right side of the travel time distribution (late arrivals) since that is the class of conditions that businesses respond to when they change delivery schedules, work schedules, and logistics practices to ensure more predictable schedules. In fact, depending on the extent of congestion, there can be conditions in which there may be relatively little difference between measuring two standard deviations to the right side of the mean, which captures 84 percent of the late situations, and a measure of buffer time that allows on-time arrival 90 percent or 95 percent of all times.

A2. Impact of Commuting Trip Costs on Productivity

Both households and businesses can be affected when travel times and vehicle operating costs increase. With the social welfare benefit concepts that underlie benefit-cost analysis, both real money costs (e.g., vehicle operating costs) and willingness-to-pay values (e.g., personal time savings) are equally counted as benefits. On the other hand, the distinction becomes of critical importance when conducting analysis of business productivity impacts because only real money effects on businesses revenues or costs count as affecting productivity.

Travel time savings for business-related work and delivery travel clearly affect productivity because workers are typically paid wages for the time involved in making those trips. Conversely, time savings for personal travel (such as trips for shopping, recreation, and visiting friends and relatives) is not counted as affecting productivity because clearly businesses do not pay for that time. An ambiguity arises for worker commuting travel. Although employees travel on their own time between home and work and they are not paid directly for that time, there is an increasingly strong base of empirical research that at least sometimes workers do receive additional compensation for working at remote, congested, or otherwise high-cost locations. And that suggests that at least sometimes, an employer may save money if transportation conditions are improved so that the “wage premium” can be diminished or eliminated. To understand this matter, it is useful to review both the theoretical and empirical research before deriving recommendations for current practice.

Evolution of Theory

Urban economic models appearing in the 1960s and 1970s showed that commuting costs can be capitalized into residential land rents, under assumptions of a monocentric urban structure in which all jobs are located in one CBD (Mills, 1967; Wheaton, 1977). By the 1980s, a second wave of models appeared that covered the case in which firms can be located in any number of different employment locations in an urban area. Under those conditions, the updated models predicted dual capitalization into both land rents and wages. The long-term equilibrium in that case has firms willing to continue to pay wage premiums associated with a given location (with perfect competition in the land and labor market) insofar as there exist location advantages that offset greater labor costs (Ogawa and Fujita, 1980; White, 1988).

Starting in 2001, a new wave of research appeared to explain that, because of heterogeneous business requirements, businesses that value clustering will choose to pay higher wages to attract workers to a clustered location. That is, there is a tradeoff in the business location decision process between the value of clustering and the wage premiums required to attract adequate labor to those more clustered locations (Timothy and Wheaton, 2001; Lucas and Rossi-Hansberg, 2002; Wheaton, 2004; Zheng et al., 2009). If there were no localized agglomeration benefits, in the long run, firms would relocate to reduce their labor costs (by reducing the commute costs of their workers), thus eliminating intra-urban wage variations. If, however, certain types of firms gain more productivity from locating within clusters while others do not, then those firms that gain from clustering will be more willing than others to continue paying wage premiums to compensate their workers for the higher commute cost (Timothy and Wheaton, 2001).

Empirical Evidence

Meanwhile, empirical evidence has been accumulating that confirms the existence of substantial intra-urban spatial variation in wage rates for the same type of job. The evidence has shown that this variation is highly correlated with, and at least partially explained by, the variation in average commuting costs to an area of employment (McMillen and Larry Singell, 1992; Van Ommeren and Rietveld, 2005; Timothy and Wheaton, 2001; Laird, 2006; Zheng et al., 2009.)

The various studies find significant variation in the wage premium depending on locations, occupations, commuting distances, and socioeconomic factors. Most of those studies, though, find that wage rate variation can cover between half and three-quarters of the variation in commuting time cost or total commuting cost.

Interpretation and Relevance for Productivity Impact Measurement

There are two explanations for this effect. Insofar as the observed conditions represent a long-term condition, the observed wage premium must be offset by some sort of agglomeration or location benefit for businesses. This may be the case in dense urban areas where certain types of businesses benefit from co-location with, or adjacency to, similar or complementary firms and activities (e.g., a high-tech R&D cluster), but commuting costs increase due to congestion effects. Alternatively, this may be the case in out-of-the-way rural locations where the firm gains from a location adjacent to resources or is sited for logistics benefit. Van Ommeren and Rietveld (2005) find evidence of the latter, noting that the marginal compensation for commuting costs in the form of wages "exceeds the marginal compensation in urban areas."

The second explanation is that some or all of the observed wage variation is only in a short-term equilibrium, or it is constrained by imperfect competition in land and labor markets. In such cases, wage premiums may be observed that are not offset by improved firm productivity. Zax (1991) explains that workers with residential mobility and access to large job markets have labor market power and therefore the capacity to shift the burden of commuting expenses onto employers, at least in the short term.

In general, the introduction of constraints on mobility for either employers or workers can lead to differential outcomes, due to "imperfect competition"—which in this case means the presence of differentiated and specialized worker skills. Regardless of the explanation, the result is that savings in commuting costs are likely to create some level of payroll savings for businesses.

Specific Recommendations

Based on evidence to date, it is recommended that productivity calculations include benefits in commuting time when certain conditions are met. The conditions are that the transportation project serves an employment center or area where employers are paying a wage premium to workers to at least partially compensate them for excess travel time and expense (or that they would be expected to do so) and reduces the need for that extra wage compensation. In doing so, a prudent approach that is supported by existing research would be to calculate the travel time compensation for commuting at one-half of the value that would be applicable for work-based travel.

The above conditions apply most clearly in situations where a project benefits commuting corridors that serve the following particular types of employment locations:

- Rural regions where a business may locate to gain proximity to input materials,
- Fringe or out-of-the-way parts of metropolitan regions where a business can gain logistical advantages for warehousing and delivery, or
- Heavily congested, high-density clusters in urban areas where a business can gain localization advantages of clustering near other complementary firms and activities.

In each of these three situations, firms locate in areas that cause their workers to incur extra travel time, vehicle operating cost or parking expenses, and they are willing to pay a compensating wage premium to attract workers there because the wage premiums are more than offset by other productivity gains associated with those locations.

There is a fourth situation in which firms also may save long-term costs because of reduced commuter expense, and that is the situation in which firms subsidize commuter transit passes, provide free parking, or grant parking subsidies for their employees. Those policies are common in some areas, and they lead to employer costs that may be reduced (in the long term) because of a transportation system improvement project. For example, a new transit line may reduce the need for employer-paid parking, thus reducing business costs.

There are no clear distinctions or boundaries defining any of the above four types of situations. Furthermore, some transportation projects may lead to commuter benefits in which a fraction of the commuting trips meets those conditions. As a result, it is up to the analyst to determine the share of commuter trips in which travel time and expense is likely to affect employer costs. A guideline is to answer the following question: *Does the project benefit commuting trips to a particular employment center, and can that area be considered to fall under any of the four situations?* Although more research is needed on this topic, the study team's recommendation is to only consider counting employee commuting benefits in cases where the answer is *yes*.

NOTE: When employers gain productivity because of a reduction in the employee compensation needed to attract workers, there are also consequences for economic impact and benefit-cost calculations. From an economic impact perspective, there is a reduction in worker income but also better cost competitiveness that can lead to more investment and ultimately more job and income growth. However, from a benefit-cost perspective, the reduction in employee compensation must be subtracted from the calculation of traveler benefits for commuting trips (to avoid double counting).

A3. Correction for Overlap and Estimation Bias

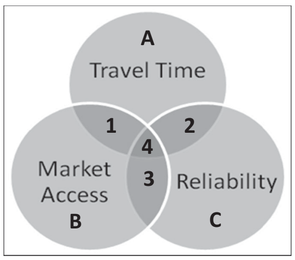


Figure A-2. Overlapping relationship of impact elements.

The wider effects of transportation projects on reliability, market access, and intermodal connectivity cannot simply be added together. The primary reason is that these elements can be correlated with each other and with traditional measures of travel time savings as illustrated in Figure A-2. The number and letter labels in the graphic are referenced in the text discussion that follows.

Key measurement issues, in terms of how they relate to the productivity impact analysis covered by this research are discussed in this section. The discussion includes recommendations regarding data refinement, analysis process modification, and interpretation of results.

(A) Travel Time Savings. There is a divergence between the social welfare (or utility) benefit measure recognized in benefit-cost analysis and the cost saving measurement recognized in productivity analysis. When assessing productivity impacts, only effects that lead to real cost savings for business activities in the study region are to be counted, as follows:

- **Trip Purposes.** For productivity impact analysis, the value of time savings should be counted only for certain classes of trip purpose: (a) business travel—in which case workers are being paid a wage or salary to cover the time, and (b) travel time to/from work—valued at a lower rate and counted when there is evidence of wage variation across the region (i.e., "wage gradient" or "wage premium" effects) that relate to differences in workplace access time and cost. This latter situation most clearly applies for commuting corridors serving business activities in rural or urban fringe areas, or urban business locations serving congested urban clusters of specialized economic activity.
- **Trip End Locations.** Some of the business-related benefits of a transportation project may be fully counted in benefit-cost analysis but should not be recognized when calculating impacts on productivity. Since the concept of productivity applies for economic activity within a defined study area, the value of time savings to business should count as a source of productivity gain only for trips that start or end within that area. Time savings for pass-through trips should not be counted at all because they would not affect the productivity of businesses inside the study area. Time savings for trips between locations inside the study area and outside locations typically should get half benefit in recognition that only one of the two trip ends is within the study area.
- **Induced Trips.** For productivity impact analysis, care should be taken to distinguish the existence and role of induced traffic. For those state DOTs and other transportation agencies that do not have travel demand models, there is a need to recognize the potential for induced traffic growth following the completion of an improvement project, as failure to do so could lead to mismeasurement of project impacts on travel time savings. However, even though induced

traffic growth is recognized, it must be evaluated in a different way for productivity impact analysis than would occur for benefit-cost analysis.

The reason for this is that productivity impact analysis focuses on real cost savings accruing to businesses in a region and does not count other aspects of benefit that may be classified as consumer surplus, which is the usual cause of induced traffic growth. The cost saving for business-generated trips that exist in both the base case and the project build case is calculated as

$$(\text{Number of Trips} * \text{Time Savings per Trip})$$

(B) Market Access. Expanded market access increases business workforce and customer opportunities, and can thus lead to agglomeration economies and related scale economies. However, there are a series of conditions under which the productivity impacts may be subject to over- or underestimation. Those situations are

- **Freight Access.** Current impact elasticity factors are based primarily on studies of effective density—a measure of surrounding economic mass that largely captures "urbanization economies." The measure also can crudely capture situations where there is some advantage of proximity to other businesses that may yield "knowledge spillovers." However, these elasticities are of limited sensitivity for manufacturing or R&D industries that are closely clustered near sources of input materials, supporting R&D resources, or intermodal transfer facilities—all forms of localization economies that depend on the locations of exogenous factors. More work is needed to refine measures of those types of localization and their benefits. Meanwhile, current productivity impact elasticities can understate productivity gains enabled by expanding same-day delivery access across freight supply chains.
- **Access Overlap.** Current methods for measuring the effect of expanding market access require a frame of reference; the current tools enable measurement of an area's effective access to surrounding population, or access to surrounding employment, buyer-supplier access, or connectivity to intermodal connectors. All of these measures depend on travel times between zones or places in a region, and they all tend to move in the same direction (increase or decrease) as a result of transportation improvements or changes in congestion levels.

  Although each of these measures focuses on a different type of trip (or trip purpose), they are not mutually exclusive in the classes of trips that they cover. In fact, currently there is no easy method to disentangle relative changes in access to labor markets, customer delivery markets, and other markets. Further research may address that issue in the future. For now, it should be recognized that inclusion of multiple access or connectivity measures can lead to some double counting of the benefit and productivity gain associated with improving regional access between zones. For this reason, it is recommended that the analyst select just one of these measures in the productivity calculation—based on whichever one appears most relevant for the particular project.

(C) Reliability. Improved travel time reliability is a form of user benefit, and reduces business costs by decreasing the need for schedule padding (i.e., buffer time). However, reliability improvements also can enable broader changes in business supply chain processes affecting inventory, safety stocks, and just-in-time processing. Although the schedule padding effect holds for both truck deliveries and business employee travel by car, the supply chain impacts are specifically related to truck deliveries. The reliability tool does separate out truck traffic from car traffic, but it does not separate business-related car trips from non-business-related car trips. To most accurately estimate the productivity impact associated with reliability changes, the analyst will need to manipulate the output of this tool to distinguish reliability effects not just by vehicle type (car/truck), but also by car trip purpose. Since car/truck traffic splits are commonly available but trip purpose data is often not available (outside of MPOs that have travel demand models), the analyst may end up calculating travel time reliability benefits only for truck trips. In that case, the total value of reliability improvements will be underestimated.

(1) Interaction of Market Access and Travel Time Impacts (A-B). Faster travel times also serve to enlarge the effective size of labor markets and customer markets, thereby increasing measures of the effective density for those markets. So, while speed benefit and market access benefit are distinct concepts, the two effects often occur together. This is particularly true for situations where transportation projects reduce traffic congestion levels, triggering both types of impacts. There is however no reason to believe the *value* of time savings is inadvertently also reflecting market access effects, since the two concepts are distinct (Venables, 2007).

Still, the estimation method used for agglomeration elasticities may lead to an upward bias on any elasticity based on generalized cost in the following situations:

- If causality/endogeneity issues exist (and are not sufficiently controlled for) between areas of high productivity and good transportation links. For instance, if areas with better transportation access attract firms employing more highly skilled workers, then the differential in value added per worker may be attributable to differences in the mix of firms and occupations.
- If the agglomeration elasticity estimate was derived from observed (ex post) changes in productivity resulting from a transportation project, and the direct benefits to firms was not taken into account (i.e., netted out).

In such cases, there is no actual double-count of time savings benefits, but the agglomeration elasticity may be upwardly biased or "over enthusiastic" in its estimate of productivity impact. The best way to minimize the problem is to carefully examine the industry mix and area context before using a given elasticity parameter. More generally, further research is needed to better refine both the measurement of agglomeration effects and elasticities used to estimate their productivity impacts.

(2) Interaction of Reliability and Travel Time Impacts (A-C). Traffic congestion (due to a high volume/capacity ratio) on a road can increase average travel times and even further increase travel time uncertainty. So, while reliability and travel time measure are completely different phenomena, they both tend to change as traffic volumes rise and resulting congestion levels increase. The methods for estimating reliability developed in the SHRP2 research, which is embedded in the reliability access tool recommended in this report, actually use this correlation to help distinguish reliability impacts from changes in average delay. As a result, the methods assume a correlation between (decreasing) reliability and increasing travel time as congestion levels rise. That in itself does not represent double counting, though it can lead to misestimation of productivity impacts if a project affects reliability for reasons other than changes in the volume/capacity ratio and corresponding congestion levels.

(3) Interaction of Market Access and Reliability Impacts (B-C). As reliability falls, commuters and delivery firms may pad schedules (departing earlier) to offset the possibility of further delays from traffic backups. This buffer increases total travel time, but also tends to reduce the breadth of truck delivery areas and the number of scheduled stops that any given delivery truck can make in a day. It also may reduce the breadth of the commuting shed or area from which a firm can attract workers. The effect on labor and delivery markets can represent a loss of business scale economies that is beyond the travel time and reliability impacts. For that reason, double counting is not necessarily involved in measuring both market access and reliability impacts, as long as reliability is not directly considered in the market access measurement.

(4) Three-Way Interactions (Travel Time, Market Access, and Reliability) (A-B-C). It is difficult to generalize the incidence of three-way interactions that can occur when a congestion bottleneck is reduced or eliminated. In such a case, there can be a simultaneous reduction in travel times, enhanced reliability, and expanded effective density or scale of market access. In general, the same types of interaction effects discussed above as Categories 1, 2, and 3, will apply in the same way previously discussed.

APPENDIX B

Calculating Agglomeration Impacts

B1. Selecting Agglomeration Metrics

Measurement Issues

The concept of agglomeration economies was introduced as an important driver of productivity gains associated with transportation projects. The use of agglomeration elasticities also has been an important part of the methodology, case studies, and tools discussed in later chapters. Yet, it is important to recognize the multi-faceted nature of agglomeration effects and the different ways that they can affect businesses, because this raises the need for further attention to detail regarding how these effects are measured and actually used to calculate productivity impacts.

Besides the concepts of localization and urbanization economies associated with agglomeration effects, the new economic geography literature looks at conflicting and competing influences associated with increased agglomeration (Krugman, 1998). On the one hand centripetal (inward) forces bring some economic activities into the core as a result of better linkages to markets, thicker (skilled) labor markets, and economies of scale. These forces compete against centrifugal (outward) forces that push other economic activities to the periphery—given the immobile factors of land and natural resources, and the spatial disbursement of markets and labor.

This leads to tradeoffs among competing factors that affect business productivity in opposite ways. In particular, congestion is a cost factor set against the economies of increased density, since increased economic activity in an area leads to increased congestion of networks and the associated added cost of increased travel times. Wage gradients (discussed earlier in Appendix A2) are real world manifestations of transportation characteristics and economic geography characteristics. They arise due to both the existence of travel time, area congestion, and agglomeration economies. Land is an immobile factor, so concentrations of activity can drive up the associated land costs in some areas and further lead to centrifugal pressure on site development at the periphery.

In the real world, business activity is multi-faceted and each type of firm has its own unique production function (i.e., recipe for use of land, buildings, labor, materials, and other factors of production, and associated quality requirements for those factors). As a result, different types of business activity operate at very different spatial scales, have widely varying responses to localization and urbanization impacts, and make very different location decisions which reflect centripetal and centrifugal forces. This is illustrated in Table B-1, which shows examples of how business locations and clusters vary in relation to transportation conditions and access features.

There is a tradeoff between use of a single, composite agglomeration metric for generic use across all types of projects, and use of different agglomeration metrics depending on the type of project and its context. An example of the former would be the UK transport project appraisal process, which imposes a consistent framework (and common agglomeration metric) for benefit-cost analysis across all projects to be considered by the central government. This same

Table B-1. Agglomeration forces affecting the location of various business types.

Business Type	Typical Location	Cluster Scale	Centripetal (Urbanization) Forces	Centrifugal (Dispersion) Forces	Cluster (Localization) Forces
Crop Farming	Non-metro	—	—	Availability & cost of farmland	—
Manufacturing of Auto Parts	Non-metro	150-mile corridor	Same-day truck delivery	Minimize land and labor cost	On highways, along supply chains, near intermodal rail
Regional Warehousing & Distribution	Periphery	—	Same-day truck delivery	Minimize land and labor cost	At highway crossroads between cities
High-Tech R&D Cluster	Urban, non-core	10 miles across	Skilled labor market	—	Medium density, areas with R&D/university access
Global Financial Center	Urban core	2 miles across	Skilled labor market, central customer access	—	High density, areas with international air service
Local Shopping	Urban (core or non-core)	0.5-mile across	Customer access (walk, drive)	—	—

approach could apply to a state DOT that wishes to assess, compare, and prioritize a large number of project proposals. An example of the latter would be the separate study of a bridge to enlarge the workforce available for a rural manufacturing plant, in which case population access may be a critical factor, or construction of a truck-only highway route to an industrial park to support growth of an automotive parts supply chain.

Recommendations

If there is a need or desire to adopt a single, composite agglomeration metric for generic use across all types of projects, and a travel demand model is available, then the single best candidate is a measure of effective density based on generalized cost (value of travel time and travel expense) between zones. The reasons are that

- An employment-density-based measure captures the economic structure of an area better than purely population-based measures, which will, however, be correlated.
- Agglomeration externalities will not be felt exclusively in one area, as the gravity model structure of the effective density measure accounts for spatial spillovers between all zones. In other words, the externality benefits are linked with the accessibility of each zone to all jobs, in a way that diminishes as the generalized cost between zones increases.

An agglomeration measure that is based on effective density can better reflect the conflicting and competing influences described above, relative to city size. For those states and areas that have no travel demand model and no ability to calculate a generalized cost, the effective density may be calculated on the basis of travel times between zones. Either way, the measure will provide sensitivity to transportation system changes that would not be available with the use of interzonal distance metrics.

Changes in effective density can occur through either reductions in the generalized cost of travel between zones or changes in the physical density of activity. Physical density changes could include an intensification of land uses in high-rise office blocks or campus-style developments around transportation hubs. Thus, an evaluation of combined transportation and land-use policies in which land uses alter in the do-something scenario should take into account these changes in physical density. The market access tool described in Section 5.3 accommodates both changes in effective density due to changes in physical density and changes in effective density due to changes in generalized cost.

If, however, there is a need or desire to specifically examine the potential productivity effects of a single major transportation investment, then there can be advantages to fine-tuning the agglomeration measurement process to most effectively capture the goals of that project, which may be to support specific types of urbanization (labor or customer market scale) or localization (cluster development) economies. For instance, if a proposed project aims to achieve better connection between manufacturing centers, or to support continued growth of a specific technology business cluster, then a metric should be selected that best captures the localization economies associated with that cluster. In that case, an effective density measure may still be used, but the decay coefficient may change and zonal characteristics may be measured in terms of activity levels applicable for the specific industry type.

Additionally, the gravity model decay coefficient may be tailored to incorporate threshold effects regarding the area applicable to a specific type of cluster that naturally occurs for some industries. The cluster area may be quite compact in the case of a high-tech cluster, or quite broad in the case of a manufacturing and supply chain cluster. See Section B3 for a discussion of these issues.

B2. Effective Density

The effective density of a single zone (j) is calculated on the basis of the activity level (e.g., employment) in surrounding zones (k) and the generalized cost of travel to those zones by various modes (m), using the formulation below:

$$Effective\ Density = ED_j = \sum_{k,m} E_k \times GC_{jkm}^{-\alpha} \qquad (1)$$

where

E_k = *workplace-based employment in k zones around and including zone j*

GC_{jkm} = *trip-weighted average generalized cost of travel between zone j and k for mode m*

α = *decay parameter.*

The larger the decay parameter α, the more rapidly effective density falls. For example, if $\alpha = -1$, the weight is precisely inverse to generalized cost. This is clearly an important parameter in the measurement of agglomeration by the effective density function, however there is a much smaller empirical base for this work. Typically, estimates of flows of goods and people with respect to generalized cost show a decay parameter of around −1, but estimates vary widely and there is no conclusion over the appropriate functional form. In the absence of better evidence, this value is appropriate, although the researchers would recommend sensitivity analysis be carried out for values of −0.5, −1, and −2. Recent work by Graham et al. (2009) specifically on distance decay function in agglomeration estimate this parameter to be about −1.1 for manufacturing and between −1.6 and −1.8 for service industries.

If modeling has been implemented using a LUTI (land-use transportation interaction) model, then resultant changes in employment should be included in the effective density calculations. If industry sector-level data is supplied then it can be run separately for different industries, which is recommended for the market access tool if there is evidence of industry specialization in one or more sectors. Otherwise, in diverse regions, the tool recommends using population measures.

Trip numbers and generalized cost are required for each origin/destination pair on the network for each scenario (including do-nothing/no-build) for each year over which the CBA is to be conducted, for each mode and purpose (business/freight/commuter).

Average generalized cost for each mode is then calculated as a trip-weighted average of all generalized costs for each mode (m) and purpose (p) between zones j and k using the given formulation

$$GC_{jkm} = \sum_p T_{jkmp} \times GC_{jkmp} \Big/ \sum_p T_{jkmp} \quad (2)$$

For each time period, the agglomeration impacts are then estimated in the following way for each sector s:

$$Y_s^{build} = \sum_k Y_{ks}^{nobuild} * \left[\left(\frac{ED_j^{build}}{ED_j^{nobuild}} \right)^{\rho_s} - 1 \right] \quad (3)$$

where

Y_s is the measure of output (GDP) per job for a given economic sector, s,
ρ_s is the agglomeration elasticity for economic sector s, and
ED is the effective density

Average annual wages for workers in each zone can be used as a basis for calculating per capita GDP for the zones selected, since GDP metrics in the United States are not available for zones smaller than MSAs. Typically, GDP averages in the range of 1.5 to 3 times wage income, depending on the area and industry.

B3. Guidance on Agglomeration Elasticities

The relationship between effective density and productivity has been established by various research studies, but there are a number of practical problems in the use of the resultant elasticities that aim to capture this relationship.

It is impossible to recommend a one-size-fits-all urbanization agglomeration elasticity. It is perhaps more sensible to consider sensitivity testing a range of values. According to the UK's Eddington (2006), "the broad consensus is that a doubling of city size is associated with an increase in productivity of 4 to 11 percent." Rosenthal and Strange (2003) find estimates typically lie between 0.03 and 0.08. The value of 0.04 also accords with the mean value of manufacturing elasticities in the Melo el al. (2009) study, although slightly lower than the value of 0.06 found by Ciccone and Hall (1996) for the manufacturing industry. For manufacturing industries the researchers would recommend using an average elasticity of 0.04, with a sensitivity range of 0.01 to 0.10. Graham et al. (2009, p. 65) notes that "estimates of urbanization economies for manufacturing range from 0.01 to 0.2, but the majority of values are under 0.1." The value of 0.04 accords with the mean value of manufacturing elasticities in the Melo et al. (2009) study and is the value that Graham (2007) finds when using a generalized cost-based measure of effective density. For service industries, the researchers recommend a value of 0.15. This accords with the mean value of service industry elasticities in Melo et al. (2009) and is consistent with the work of Graham (2007, 2009) which shows a sensitivity range of 0.05–0.40. The lower bound of this range encompasses service-based elasticities reported by Alstadt and Weisbrod (2012), while the higher bound reflects elasticities found in some service sectors by Graham (2007b).

If users wish to employ their own measures there are a number of considerations to make, which are discuss below. Also discussed is the use of localization elasticities.

Sources of Variance in Elasticity Measures

Recent meta-analysis work clearly shows how these elasticities differ. Melo et al. (2009) show how estimates of urban agglomeration economies vary, based on 729 estimates from 34 studies between 1965 and 2002. The ranges are driven by a number of dimensions as follows:

- **Economic Sector.** Professional service and banking/finance industries generally exhibit higher elasticities of urban agglomeration than manufacturing industries. This is reflected in their greater preference for central urban locations that maximize access to markets and/or other services. In contrast, manufacturing sites tend to have a lower elasticity, and are more likely to be found on the periphery of urban areas. This finding is supported by Alstadt et al. (2012), who find a range of elasticities for labor market access from .01 to .04 for manufacturing, and from .05 to .10 for professional services. Graham (2007) finds the highest elasticities to be for banking, finance, and business services (.22 to .24), with the lowest for manufacturing and construction (.07 to .08).
- **Measurement of Productivity and Agglomeration.** Values for agglomeration effects also vary depending on the form of market potential (zonal activity) measure that is used to measure agglomeration, which may reflect employment by workplace zone or either labor force or total population by residence zone.

Studies using the wage measure of productivity found lower elasticities than total factor productivity methods.

- **Study Area.** North American–based estimates are generally found to be slightly lower than those derived from European studies, all else constant.
- **Aggregation.** Aggregate data rather than individual firm-level data also yield lower estimates. Firm-level data is likely to yield a more reliable estimate of elasticities given the micro scale at which agglomeration impacts play out.
- **Control Variables.** Estimates that control for skilled labor also are considerably lower, i.e., some of the productivity improvement is due to skilled workers being attracted to denser areas, so estimates that do not control for this will be upwardly biased. UK-based estimates that control for endogeneity and labor quality are smaller than elsewhere. Graham et al. (2009) finds estimates ranging from .08 for business services, to .02 for manufacturing and consumer services for a doubling of city size.

Estimates that simultaneously control for localization elasticities yield lower estimates. Localization and urbanization elasticities are likely to be highly positively correlated, so if localization measures are omitted from the estimation procedure, the associated productivity impacts will be attributed to the urbanization measure.

- **Estimation Method.** Fixed-effects-based estimates are found to be lower than cross-sectional, as these control for time invariant cross-sectional differences in productivity.

Summary statistics from a range of studies featured by Melo et al. (2009) are shown in Table B-2, by location, industry group, and type of agglomeration measure used.

Raw figures vary widely, between –0.8 (with negative numbers indicating productivity diseconomies) and 0.658, with a mean of 0.058, i.e., 5.8 percent. The mean figure for U.S.-based studies is .036. These raw figures indicate higher elasticities for service industries.

The meta analysis work is based on regressions that control for differences in study design, using variables to account for time periods, area, sector, data type, geographical areas, human capital, estimation method, agglomeration measure, agglomeration specification (i.e., whether it includes a measure of localization as well as urbanization), and the productivity measure (i.e., the dependent variable).

Table B-2. Summary statistics from Melo et al. (2009).

Sample	Obs.	%	Mean	Median	SD	Min	Max
Estimates	729	100	0.058	0.041	0.115	-0.800	0.658
Studies	34	100	0.043	0.037	0.055	-0.088	0.194
By country/region							
Brazil	20	2.74	0.046	0.024	0.052	0.003	0.180
Canada	14	1.92	-0.003	0.028	0.151	-0.310	0.300
China	2	0.27	0.013	0.013	0.028	-0.007	0.033
Europe	21	2.88	-0.038	0.045	0.258	-0.800	0.280
France	54	7.41	0.039	0.035	0.022	0.012	0.143
India	18	2.47	0.017	0.007	0.179	-0.204	0.658
Italy	43	5.90	0.041	0.031	0.032	0.002	0.109
Japan	115	15.78	0.048	0.040	0.060	-0.079	0.300
Sweden	4	0.55	0.017	0.018	0.002	0.014	0.019
UK/GB	254	34.84	0.102	0.083	0.145	-0.277	0.503
United States	184	25.24	0.036	0.036	0.064	-0.366	0.319
By measure of agglomeration							
Market potential/distance band	279	38.27	0.101	0.076	0.143	-0.277	0.658
Density	158	21.67	0.030	0.039	0.099	-0.800	0.300
Size	292	40.05	0.032	0.030	0.076	-0.410	0.319
By measure of productivity							
Labor productivity	342	46.91	0.053	0.038	0.095	-0.366	0.503
Output	264	36.21	0.076	0.057	0.156	-0.800	0.658
Wages	123	16.87	0.034	0.032	0.030	-0.096	0.143
By industry group							
Overall economy	168	23.05	0.031	0.034	0.099	-0.800	0.250
Manufacturing	427	58.57	0.040	0.036	0.095	-0.366	0.658
Services	134	18.38	0.148	0.142	0.148	-0.219	0.500

Localization vs. Urbanization Elasticities

Localization elasticities are theoretically distinct from urbanization elasticities because they occur due to connectivity economies through increased scale of an industry rather than the increased market access through a larger urban area. As such, they are thought to occur due to geographical proximity between firms enabling better communication and lower cost supply networks and benefits through a shared labor pool.

There is a small body of literature underpinning estimates of localization elasticities, and their impact varies depending on the geographic and industrial scope, data, and estimation techniques. The evidence suggests these economies impact over short distances (i.e., the impacts decay rapidly with distance) and are relatively larger for more specialized manufacturing industries than for service industries.

Although the distinction between urbanization and localization elasticities is conceptually clear, in practice it is hard make a clear distinction because they can occur simultaneously in dense urban areas, and their effects on business location can be confounded. The parallel existence of urbanization and localization agglomeration economies makes it important, though not easy, to distinguish between market access (urbanization type effects) and connectivity (localization type effects)—a point emphasized by Ellison et al. (2007).

Ideally one should use an agglomeration elasticity pertinent to the relevant type of activity or business cluster. However, empirical difficulties in differentiating these elasticities mean that the choice of available elasticity estimates is small. It is possible that no elasticity is available that perfectly fits the local economic geography but a composite may be derived from several elements. For example, it may be felt that a mixture of localization and urbanization economies is at play.

It is not possible to sensibly offer a range of sensitivities here but to note that some reported elasticities in joint studies are higher than those for urbanization elasticities (e.g., Rosenthal and Strange, 2003). Estimates of localization elasticities are primarily for manufacturing industries. Recent work (Graham et al., 2009) finds an average localization elasticity within 10 km of the firm of 0.03 for manufacturing and 0.01 for services—this hides the fact that some service sectors have high elasticities while others are very low, so it is appropriate to seek out industry-specific values.

Applying two elasticities (one for urbanization and one for localization) and summing the resulting productivity impacts would be ideal if there were appropriate elasticity values that actually isolated the two effects. However, further research is necessary to achieve that state of practice. In the meantime, efforts to apply two separate elasticities will overestimate the total productivity impact—as it is likely that localization economies were not controlled for when estimating the urbanization elasticity and vice versa. (That is indeed the case for the recommended elasticity values that were presented in Table 3-9 and applied in the Chapter 4 case studies.) So the current recommendation is to use one elasticity per category of business activity. The choice of whether to use a localization elasticity or an urbanization elasticity for any given type of business should be determined by the economic characteristics of the area.

APPENDIX C

Directions for Future Research

Updating

This report sets forth a general framework for analysis of the direct productivity impacts of transportation projects. The framework, including guidelines for measurement and rules for calculation, is intended to encourage implementation while informing readers about where it is necessary to look for bias and double counting problems. That being said, it is also clear that there is substantial opportunity for refinement of data, measurement, and impact calculations to improve the accuracy and usefulness of this process. For that reason, the specific threshold, coefficient, and elasticity factors recommended in Chapter 3 should be seen as initial values updated in the future. Likewise, the spreadsheet tools introduced in Chapter 5 should be seen as functional but illustrative models that can (and should) be improved upon in the future.

Areas for Research Improvement

Discussion with transportation agency staff and researchers, conducted for this study, indicated that there are many issues that are touched upon by the research but require further research that is outside of the scope of this project. This includes research and guidance on how to

- Best measure changes in accessibility and network connectivity for different types of projects in different settings or contexts;
- Better understand (and measure) supply chain impacts by updating transportation satellite accounts and measuring inventory/stocking patterns;
- Note if productivity changes will affect subsequent business investment and attraction;
- Compare projects spanning different modes on a fair and consistent basis;
- Recapture private sector benefits that result from transportation investment;
- Assess economic benefits of small projects such as highway interchanges; and
- Better communicate to audiences so as to attract more investment and raise revenue to support strategic transportation investments.

Areas for Tool Improvement

Beside further research, it was noted that more work is needed to develop and enhance analysis tools for measuring the impacts of transportation projects on reliability, intermodal connectivity, and market access (agglomeration effects). For the latter, there is a need for specific attention to the distinction between localization (business cluster) benefits and urbanization (market access) impacts on productivity that are both enabled by improving accessibility.

Additionally, it was noted that current tools are generally limited to urban road and urban public transportation projects, and projects affecting regional truck delivery. Tools to address productivity impacts of other modes (e.g., air, marine, and intercity rail) are less available. Even the currently available highway impact tools are of limited use for projects affecting intercity travel.

Looking to the future, there are substantial opportunities to improve the estimation of productivity impacts through better integration of travel demand models with regional land-use and economic models.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation