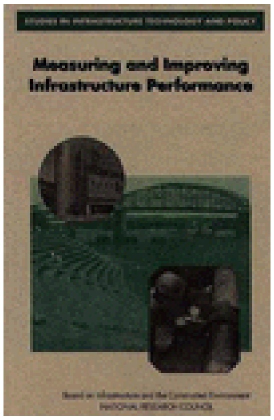
http://www.nap.edu/catalog/4929.html
We ship printed books within 1 business day; personal PDFs are available immediately.



Measuring and Improving Infrastructure Performance

Committee on Measuring and Improving Infrastructure Performance, National Research Council

ISBN: 0-309-58710-7, 132 pages, 6 x 9, (1996)

This PDF is available from the National Academies Press at: http://www.nap.edu/catalog/4929.html

Visit the National Academies Press online, the authoritative source for all books from the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine, and the National Research Council:

- Download hundreds of free books in PDF
- Read thousands of books online for free
- Explore our innovative research tools – try the “Research Dashboard” now!
- Sign up to be notified when new books are published
- Purchase printed books and selected PDF files

Thank you for downloading this PDF. If you have comments, questions or just want more information about the books published by the National Academies Press, you may contact our customer service department toll-free at 888-624-8373, visit us online, or send an email to feedback@nap.edu.

This book plus thousands more are available at http://www.nap.edu.

Copyright © National Academy of Sciences. All rights reserved.
Unless otherwise indicated, all materials in this PDF File are copyrighted by the National Academy of Sciences. Distribution, posting, or copying is strictly prohibited without written permission of the National Academies Press. Request reprint permission for this book.

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Measuring and Improving Infrastructure Performance

COMMITTEE ON MEASURING AND IMPROVING INFRASTRUCTURE PERFORMANCE
BOARD ON INFRASTRUCTURE AND THE CONSTRUCTED ENVIRONMENT
COMMISSION ON ENGINEERING AND TECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1995

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of 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. Bruce M. Alberts 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. Robert M. White 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. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was established 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 of 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. Bruce M. Alberts and Dr. Robert M. White are chairman and vice-chairman, respectively, of the National Research Council.

Funding for the project was provided through the following contract with the Department of the Army Corps of Engineers, Contract No. DACW72-93-C-004.

Library of Congress Catalog Card Number: 95-68207
International Standard Book Number: 0-309-05098-7
Additional copies of this report are available from: National Academy Press 2101 Constitution Avenue, NW Box 285 Washington, D.C. 20055 800-624-6242 or 202-334-3313 (in the Washington Metropolitan area)

Copyright 1995 by the National Academy of Sciences. All rights reserved.

Printed in the United States of America.

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

COMMITTEE ON MEASURING AND IMPROVING INFRASTRUCTURE PERFORMANCE

JARED L. COHON, *Chair*, Dean, School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut

W. BRUCE ALLEN, Professor of Public Policy and Management, The Wharton School, University of Pennsylvania, Philadelphia

L. G. (GARY) BYRD, Consulting Engineer, Alexandria, Virginia

RANDALL W. EBERTS, Executive Director, W.E. Upjohn Institute for Employment Research, Kalamazoo, Michigan

HUGH ELLIS, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, Maryland

HAROLD T. GLASER, Vice President, Montgomery Watson, Pasadena, California

GARETH M. GREEN, Associate Dean for Professional Education and Director, Master of Public Health Programs, Harvard School of Public Health, Boston, Massachusetts

FRANNIE HUMPLICK, Infrastructure Economist, The World Bank, Washington, D.C.

ELLIS L. JOHNSON, Professor of School of Industry and Systems Engineering, Georgia Institute of Technology, Atlanta

LANCE A. NEUMANN, President, Cambridge Systematics, Inc., Cambridge, Massachusetts

VIET NGO, P.E., President, Lemna Corporation, Mendota Heights, Minnesota

SERGIO RODRIGUEZ, AICP, Assistant City Manager, Planning, Building and Zoning Department, City of Miami, Florida

GEORGE ROWE, Consultant, Cincinnati, Ohio

KENNETH I. RUBIN, President, Apogee Research Inc., Bethesda, Maryland

IRAJ ZANDI, Professor of Systems and National Center Professor of Resource Management and Technology, Department of Systems, University of Pennsylvania, Philadelphia

Sponsor Liaisons

EUGENE Z. STAKHIV, Chief, Policy Division, Institute for Water Resources, Fort Belvoir, Virginia

JAMES F. THOMPSON, JR., Analyst, Engineers Strategic Studies Center, Fort Belvoir, Virginia

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Other Government Liaisons

KEN CHONG, Director, Structural Systems and Construction Processes, National Science Foundation, Arlington, Virginia
CHARLES W. NEISSNER, Research Highway Engineer, Office of Advanced Research, Federal Highway Administration, McLean, Virginia
JOHN B. SCALZI, Program Director for Structures and Building Systems, National Science Foundation, Arlington, Virginia
JOHN SMART, Chief, Civil Engineering Division, Bureau of Reclamation, Denver, Colorado

Staff

ANDREW C. LEMER, Director
SUSAN COPPINGER, Administrative Assistant
SUSAN MORGAN, Administrative Assistant
MARY McCORMACK, Project Assistant

Copyright © National Academy of Sciences. All rights reserved.

BOARD ON INFRASTRUCTURE AND THE CONSTRUCTED ENVIRONMENT (SINCE 1994)

GEORGE BUGLIARELLO, *Chair*, Chancellor, Polytechnic University, Brooklyn, New York
CATHERINE BROWN, Director of Special Projects, Design Center for American Urban Landscape, University of Minnesota, Minneapolis
NANCY RUTLEDGE CONNERY, Consultant, Public Works Infrastructure, Woolwich, Maine
LLOYD A DUSCHA, Consulting Engineer, Reston, Virginia
ALBERT A. GRANT, Consulting Engineer, Potomac, Maryland
E. R. HEIBERG III, Consultant, Mason Neck, Virginia
RONALD W. JENSEN, Public Works Director, City of Phoenix, Arizona
JAMES K. MITCHELL, Charles E. Via, Jr., Professor of Civil Engineering, Virginia Polytechnic Institute, Blacksburg
HAROLD J. P MELEE, President, Turner Construction Company, New York, New York
STANLEY W. SMITH, Consultant, McLean, Virginia
RAYMOND L. STERLING, Shimizu Professor of Civil and Mineral Engineering, Director, Underground Space Center, University of Minnesota, Minneapolis

Staff

DENNIS CHAMOT, Director
HENRY A. BORGER, Executive Secretary, Federal Construction Council
SUSAN COPPINGER, Administrative Assistant
LENA B. GRAYSON, Program Assistant

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

BUILDING RESEARCH BOARD (1993-1994)

HAROLD J. PARMELEE, Chair, President, Turner Construction Company, New York, New York
LYNN S. BEEDLE, University Distinguished Professor of Civil Engineering and Director, Council on Tall Buildings and Urban Habitat, Lehigh University, Bethlehem, Pennsylvania
CATHERINE BROWN, Director of Special Projects, Design Center for American Urban Landscape, University of Minnesota, Minneapolis
NANCY RUTLEDGE CONNERY, Consultant, Woolwich, Maine
AUGUSTINE A. DiGIACOMO, Partner, Jaros, Baum, and Bolles, Consulting Engineers, New York, New York
DELON HAMPTON, Delon Hampton & Associates, Washington, D.C.
DONALD G. ISELIN, U.S.N. Retired, Consultant, Santa Barbara, California
GARY T. MOORE, Professor of Architecture and Director, Wisconsin Space Grant Consortium, University of Wisconsin, Milwaukee
WALTER P. MOORE, President and Chairman of the Board, Walter P. Moore and Associates, Inc., Houston, Texas
J. W. MORRIS, U.S.A. Retired, President, J. W. Morris Ltd., Arlington, Virginia
BRIAN P. MURPHY, Senior Vice President, Prudential Property Company, Prudential Plaza, Newark, New Jersey
JEROME J. SINCOFF, American Institute of Architects, President, Hellmuth, Obata & Kassabaum, Inc., St. Louis, Missouri

Staff

ANDREW C. LEMER, Director (1988-1993)
HENRY A. BORGER, Executive Secretary, Federal Facilities Council
LENA B. GRAYSON, Program Assistant
MARY McCORMACK, Project Assistant

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

TABLE OF CONTENTS

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

LIST OF FIGURES

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

LIST OF TABLES

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

EXECUTIVE SUMMARY

The nation's infrastructure facilitates movement of people and goods, provides adequate safe water for drinking and other uses, provides energy where it is needed, removes wastes, and generally supports our economy and quality of life. Determining how well infrastructure is performing these tasks is essential to effective management of the assets infrastructure represents. Yet current practices for measuring performance are largely inadequate to respond to this management task. Responsibility for these valuable assets is primarily a local matter, with some 80 percent of the annual investment in infrastructure coming from local and state government sources or private enterprises. Nevertheless the federal government's influence on infrastructure development and management is substantial, exercised through many programs that provide funds for purchasing and construction, set standards, and otherwise seek to ensure the safety and efficacy of various parts of the nation's infrastructure. There currently is no integrated federal policy toward infrastructure as a whole. The Federal Infrastructure Strategy (FIS) is a three-year, interagency program directed and administered by the U.S. Army Corps of Engineers (USACE) to provide the substantive framework for determining whether such a policy is warranted and what its content might be.

SOURCE OF THIS STUDY

As a part of the FIS program, the USACE requested the National Research Council (NRC) to undertake a study on measuring and improving infrastructure performance. The NRC appointed the Committee on

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Measuring and Improving Infrastructure Performance, which started its work in October 1993 and met five times during a period of about 10 months. To provide a practical background for its study and to explore how concepts of performance are used by decision makers, the committee visited three titles selected to represent situations in which performance measures might be used: Baltimore, Maryland; Portland, Oregon; and Minneapolis-St. Paul, Minnesota. During these visits, the committee met with government officials and other knowledgeable professionals in each area to discuss particular projects and the region's infrastructure more generally. This document is a report of the committee's work. Principal findings and recommendations are summarized in tables ES-1 and ES-2 and on the following pages.

THE STUDY'S FOCUS AND LIMITS

The committee's point of departure was the work of the National Council on Public Works Improvement (NCPWI), embodied in the council's 1988 final report, *Fragile Foundations*. The committee's scope was limited from the study's start to the specific modes of infrastructure addressed in that report. For much of their discussion, the committee grouped these modes into four broad categories: (1) transportation, including highways, mass transit, and aviation; (2) water, including water resources and water supply; (3) wastewater (both sanitary sewage and stormwater runoff); and (4) municipal waste, including both solid and hazardous wastes. Other infrastructure modes, such as telecommunications, energy production and distribution, and parks and open space inevitably entered the committee's discussion but are beyond the scope of this report. However, the committee sought to generalize their discussions and to deal with performance of infrastructure as an integrated, multifunctional system. Many of the principles and recommendations discussed here apply to all infrastructure modes as a single system.

Infrastructure is built and serves regions on many scales, but the committee focused on issues arising from transportation, water, and waste within urban regions. The organizational context of these issues is primarily local governments, multijurisdictional bodies (e.g., regional councils), and states. This study's systemwide approach, that is, looking across infrastructure modes (water, transportation, wastewater, solid wastes) to define performance in an urban region, runs counter to the typical institutional structure of infrastructure. This institutional structure now consists largely of organizations concerned with both programs and projects within a single mode. Critics cite this structure as an obstacle to improved performance of the nation's infrastructure as a whole because it deters effective thinking about the interactions and tradeoffs among the various modes.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

TABLE ES-1 Summary of Principal Findings and Conclusions

Infrastructure Performance and its Measurement

1. Infrastructure constitutes valuable assets that provide a broad range of services at national, state, and local levels. Its performance is defined by the degree to which the system serves multilevel community objectives. Identifying these objectives and assessing and improving infrastructure performance occur through an essentially political process involving multiple stakeholders.

2. Performance measurement, a technical component of the broader task of performance assessment, is an essential step in effective decision making aimed at achieving improved performance of these valuable assets.

3. Despite the importance of measurement, current practices of measuring comprehensive system performance are generally inadequate. Most current measurement efforts are undertaken because they are mandated by federal or state governments or as an ad hoc response to a perceived problem or the demands of an impending short-term project.

4. No adequate, single measure of performance has been identified, nor should there be an expectation that one will emerge. Infrastructure systems are built and operated to meet basic but varied and complex social needs. Their performance must therefore be measured in the context of social objectives and the multiplicity of stakeholders who use and are affected by infrastructure systems.

5. Performance should be assessed on the basis of multiple measures chosen to reflect community objectives, which may conflict. Some performance measures are likely to be location-and situation-specific, but others have broad relevance. Performance benchmarks based on broad experience can be developed as helpful guides for decision makers.

6. The specific measures that communities use to characterize infrastructure performance may often be grouped into three broad categories: effectiveness, reliability, and cost. Each of these categories is itself multidimensional, and the specific measures used will depend on the location and nature of the problem to be decided.

Assessment Process

7. The performance assessment process by which objectives are defined, specific measures specified and conflicts among criteria reconciled is crucial. It is through this process that community values are articulated and decisions made about infrastructure development and management.

8. Methodologies do exist for structuring decision making that involve multiple stakeholders and criteria, but experience is limited in applying these methodologies to infrastructure.

9. Performance assessment requires good data. Continuing, coordinated data collection and monitoring are needed to establish benchmarking and performance assessment.

10. The subsystems of infrastructure—transportation, water, wastewater, hazardous and solid waste management, and others—exhibit both important physical interactions and relationships in budgeting and management. Effective performance management requires a broad systems perspective that encompasses these interactions and relationships. Most infrastructure institutions and analytical methodologies currently do not reflect this broad systems perspective.

11. The long-term and sometimes unintended consequences of infrastructure systems, whether beneficial or detrimental, frequently go far beyond the physical installations themselves. Community views of these consequences become a part of the assessment and decision-making process.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

TABLE ES-2 Summary of Recommendations

1. Local agencies with responsibilities for infrastructure management should explicitly define a comprehensive set of performance measures and set aside funds sufficient to sustain an adequate performance measurement process. The measures selected should reflect the concerns of stakeholders about the important consequences of infrastructure systems and recognize interrelationships across infrastructure modes and jurisdictions. The committee's framework of effectiveness, reliability, and cost is a useful basis for establishing these measures.
2. While not every aspect of performance is quantifiable, attempts should be made to devise quantitative indicators of qualitative aspects of performance. Quantitative measures should then be used to develop benchmarks that policy makers responsible for assessing infrastructure performance can use for setting goals and comparing performance among systems, considering effectiveness, reliability, and costs (including actual expenditures as compared to budgets).
3. Recognizing that infrastructure performance cannot be managed if it cannot be measured, data should be collected on a continuing basis to enable long-term performance measurement and assessment.
   a. Each region with infrastructure decision-making authority should establish a system for continuing data collection to give performance assessment a more quantitative basis and enable longer term performance monitoring. Metropolitan areas with basic databases and modeling tools already in place should seek to integrate information on separate infrastructure modes into a uniform and accessible system, so that existing data sets are documented in consistent ways, within the context of relevant national data collection activities (e.g., federal Department of Transportation or Environmental Protection Agency statistics).
   b. Federal agencies should assure that national data sets (that is, those collected by or under the requirements of federal programs), are compatible (e.g., in geographic detail, time periods, and indexing), computerized, and made electronically accessible.
   c. All such performance data collection should be designed to facilitate benchmarking.
   d. New data collection activities should give priority to those functional areas where data currently are sparse (e.g., highway stormwater runoff characteristics, solid waste recycling reliability).
4. Responsible agencies should adopt infrastructure performance measurement and assessment as an ongoing process essential to effective decision making. The selected set of performance measures should be periodically reviewed and revised as needed to respond to changing objectives, budgetary constraints, and regulations.
5. Responsible agencies should undertake a critical self-assessment to determine the nature and extent of specific regulations, organizational relationships, jurisdictional limitations, customary practices, or other factors that may constitute impediments to adoption of the proposed infrastructure performance measurement framework and assessment process. Such a self-assessment could be conducted within the context of a specific infrastructure management problem or as a generic review, but it necessarily will involve time, money, and a concerted effort to motivate active community involvement with open, candid discussion. The assessment should conclude with explicit recommendations of institutional change that may be needed to enable a systemwide approach to management of infrastructure performance.
6. Federal infrastructure policy and regulations should be revised as needed to accommodate local decision-making processes and performance measurement frameworks within the context of valid national interests in local infrastructure performance. Federal policy effectiveness should be evaluated on the basis of its sensitivity to local variations in performance assessment.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

The purpose of measuring performance is to support those who must make decisions about developing, operating, and maintaining infrastructure. These individuals are typically elected officials and the senior technical administrators in a region, for example, public works directors and planning directors. This latter group must on the one hand advise elected officials and the public on infrastructure and on the other hand direct the development and operations of infrastructure facilities and services. Likely the primary users of the committee's work, these individuals must assess how well infrastructure is performing its expected tasks.

The committee's work will result in a framework and process for measuring and assessing infrastructure performance that local decision makers and others concerned with development and management can use as a basis for discussion and action to enhance infrastructure's contribution to achieving their community's goals.

While the committee initially considered the premise that infrastructure performance measurement must occur within the existing institutional framework, its visits to Baltimore, Portland, and Minneapolis-St. Paul illustrated that institutional setting is crucial, that a variety of institutional structures are possible, and that changes can be made when change is warranted. The committee believes that in many areas institutional change may be needed over the longer term to permit the truly multijurisdictional and multimodal infrastructure management that will enable infrastructure systems to achieve their best performance.

DEFINING INFRASTRUCTURE PERFORMANCE

Generally, performance is the carrying out of a task or fulfillment of some promise or claim, and for infrastructure this means providing or enabling movement of goods and people, clean water supplies, waste disposal, and a variety of other services that support other economic and social activities, a safe and healthful environment, and a sustainably high quality of life. Infrastructure is a means to other ends, and the effectiveness, efficiency, and reliability of its contribution to these other ends must ultimately be the measures of infrastructure performance.

Judging whether performance is good or bad, adequate or inadequate, depends on the community's objectives. These objectives are generally set locally but include state and federal elements and widely accepted standards of practice. Performance must ultimately be assessed by the people who own, build, operate, use, or are neighbors to that infrastructure. The committee found that there are few benchmarks or norms of performance that apply to infrastructure as a system, or even that apply comprehensively to all aspects of performance of any one type of infrastructure. More benchmarks are needed to give decision makers a broad basis for judgments about infrastructure performance.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

While infrastructure is owned and operated by private enterprises as well as government agencies, its fundamental role makes infrastructure a public asset. Judgments about the adequacy of performance are typically made in a public setting. Many individuals and institutional and corporate entities make up the "community" that has a stake in infrastructure performance, and each stakeholder's view must be considered in assessing that performance. These individuals include providers of infrastructure services and individuals, households, and businesses that use infrastructure and are exposed to infrastructure's impacts. These stakeholders' perspectives focus at the level of city or county, state or province, nation, or broader, in watersheds, airsheds, neighborhoods, historic districts, and other naturally, socially, or economically defined areas. Reaching consensus can be difficult. Even when one person has clearly defined responsibility for making investments or operating decisions about some element of infrastructure, that person must be prepared for public scrutiny of his or her premises and conclusions.

The assessment process must ensure broad participation in making the judgment and determining the bases on which judgment is to be made. In short, infrastructure performance is defined by the community, and its measurement must start with the tasks the community wants its infrastructure to accomplish. This community, however, is inevitably broad and diverse, including regional and national as well as local perspectives.

Because of these many facets of infrastructure performance and its assessment, no single performance measure has yet been devised, nor is it likely that one can be. Infrastructure performance measurement must be multidimensional, reflecting the full range of the social objectives set for the infrastructure system. The committee nevertheless found that performance—the degree to which infrastructure provides the services that the community expects of that infrastructure—may be defined as a function of *effectiveness, reliability*, and *cost*. Infrastructure that reliably meets or exceeds community expectations, at an acceptably low cost, is performing well. The three principal dimensions of performance are each, in turn, complex and multifaceted, typically requiring several measures to indicate how well infrastructure is performing.

The challenge decision makers face in seeking to develop and manage infrastructure for high performance is one of applying money, land, energy, and other resources to deliver effective and reliable service to the broad community. These resources are used in planning, construction, operation, maintenance, and sometimes demolition of facilities; monitoring and regulating the safety and environmental consequences of these activities; and mitigating adverse impacts of infrastructure. The costs are incurred and paid at different times and places, by different agencies and groups (e.g., users, neighbors, taxpayers), and in nonmonetary and mone

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

tary terms. Decisions are made in an uncertain world, with limits to how accurately effectiveness and cost can be measured. Storms, accidents, and sudden failure of materials and equipment can drastically alter the relationship of cost and effectiveness. Assessing performance is a way of dealing with effectiveness, reliability, and costs in an orderly manner to enable decisions to be made about the infrastructure system.

ASSESSING PERFORMANCE AND DECISION MAKING

Figure ES-1 illustrates the committee's concept of a generic assessment process. The first step is to clearly identify who the stakeholders are in the decision-making situation that motivates the assessment. The level at which the decision is made (e.g., local or state) and the type of decision (e.g., planning new facilities, determining how to implement a new regulation) will have much to do with who these stakeholders are.

The next steps deal with clearly defining the infrastructure system of interest, the boundaries and context of the system and area served, the objectives and vision the community sets for the system, and constraints (e.g., budgets, interagency relationships, jurisdictional constraints) and regulations that may limit feasibility of actions. Table ES-3 summarizes the types of information that such an inventory of the infrastructure system is likely to include and presents examples of specific indicators.

This inventory involves the use of databases of the types typically maintained by municipal and regional planning agencies, departments of transportation, water utilities, and sewer authorities. Few areas have brought these typically distinct databases together into a comprehensive resource that will support effective performance assessment. The opportunities for assembling such comprehensive databases are growing as data increasingly are being stored in highly accessible, computer-based geographical information systems that provide a common framework for storage, retrieval, and analysis.

Selecting measures and measuring performance are central tasks in assessment and may sometimes involve a substantial amount of public discussion. The specific measures may have general use but should always be appropriate for the particular situation being assessed. Local values have overarching influence on the selection and on all other steps in the assessment process.

The assessment process will yield a multidimensional set of specific measurements (qualitative as well as quantitative) of key indicators of performance. These measurements may be used by decision makers to decide what should be done to address the problem or demand or to realize the vision that motivated assessment. Tables ES-4, ES-5, and ES-6 make up the committee's performance measurement framework. These tables illustrate

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

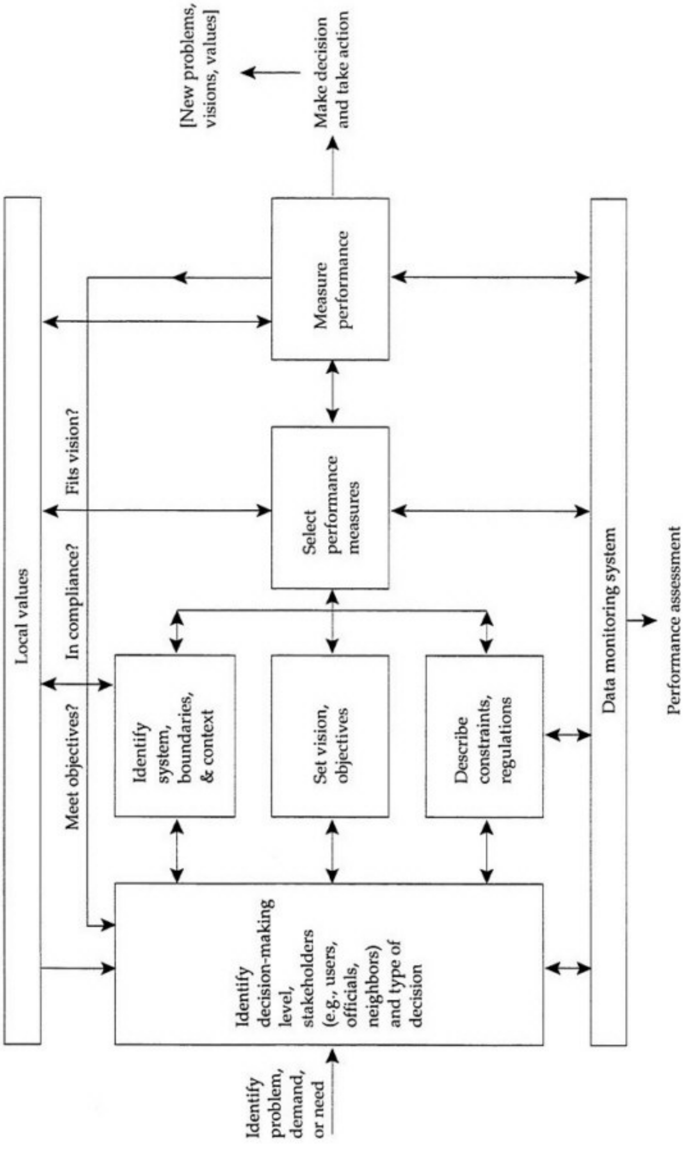


FIGURE ES-1 Performance assessment as a generic process.

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE ES-3 Framework and Measures of System Inventory*

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
Generic: all elements or types		
• Enhance economic productivity, opportunity • Improve public health, safety • Protect, enhance environmental quality • Provide jobs and economic stimulus • Reduce income inequalities	• System size • Condition • System cost • Technology • Area of extent	• Political jurisdictions • Formal institutions • Informal, community structure
Examples for Major Classes		
Transportation Systems		
• Improve access • Increase mobility • Move goods efficiently • Protect safety • Reduce air pollution • Increase construction spending • Subsidize public transit operations	• System size – Lane-miles, track-miles – Number of bridges, airports – Fleet size and mix – Area covered, network configuration – Runway length, terminal gates • Condition – Pavement cracking – Bridge load capacity – Track condition • System cost – Replacement cost (construction) – Annual O&M expenditures • Technology – Fuel types – Fleet age distribution • Area of extent – Natural barriers – Airsheds, basins	• Political jurisdictions – System ownership – Pricing authority – Funding and taxing arrangements • Formal institutions – Construction – Operations – Intermodal coordination • Informal, community structure – Ridership – Advocacy groups (e.g., bicycle, pedestrian) – Land developers – Business groups – Environmental resistance groups (e.g., airport noise) – Neighborhood associations
Water Supply		
• Provide adequate, reliable, sources of water • Protect and improve public health • Provide fire protection • Enable and support landscaping, gardening, agriculture • Provide recreation and environmental amenity • Support biodiversity	• System size – Miles of main, distributer – Number of reservoirs, treatment plants – Area piped – Total storage capacity • Condition – Pipe leakage – Reservoir percent of design capacity – Design supply (treatment) capacity • System cost – Replacement cost (construction) – Annual O&M expenditures	• Political jurisdictions – System ownership – Rate-setting, financing – Consumers, service area – Supply sources • Formal institutions – Utility – Regulatory authorities – Bonding, financing authorities • Informal, community structure – Land developers – Major users (e.g., industries) – Recreation interests

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE ES-3

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
	• Technology – Treatment process – Supply main materials • Area of extent – Drainage basins – Catchment areas – Recharge areas	
Wastewater (Sewage and stormwater) • Remove sanitary, industrial wastes • Control, reduce health hazard • Provide flood control, protection	• System size – Miles of main, collector – Number of treatment plants – Area sewered – Separate/ combined system • Condition – Pipe leakage, infiltration – Plant percent of design capacity • System cost – Replacement cost (construction) – Annual O&M expenditures – Average unit treatment cost • Technology – Treatment process – Main materials • Area extent – Drainage basins – Recharge areas – Ecosystems, biomes	• Political jurisdictions – System ownership – Service area – Rate setting, financing – Receiving waters – Disposal sites • Formal institutions – Construction – Operations – Maintenance – Regulatory authorities • Informal, community structure – Major producers (e.g., industrial concerns) – Advocacy groups – Treatment and disposal neighbors – Recreational interests
Municipal Waste • Remove wastes • Reduce materials consumption • Avoid exposure of low-income people to toxic materials	• System size – Number of collection vehicles – Number of collection, transfer, disposal sites, facilities – Landfill design capacity – Labor force • Condition – Incinerator age – Landfill percent of design capacity – Haul distance • System cost – Replacement cost (construction) – Annual O&M expenditures	• Political jurisdictions – Collection areas – Disposal sites – Transportation routes • Formal institutions – Municipal agencies – Concessionaires, contractors – Recycling and disposal firms – Regulatory agencies • Informal, community structure – Major producers (e.g., industrial concerns) – Advocacy groups – Treatment and disposal neighbors

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

the primary dimensions of performance and typical measures of effectiveness, reliability, and cost. The specific measures included in the tables represent a comprehensive but not necessarily complete listing that users might augment or narrow to suit their particular decision-making situation.

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
	• Technology - Disposal system and process - Recycling processes • Area extent - Ecosystems, biomes - Airsheds - Groundwater regimes	

* Assessment may be made at local, regional, or national level; level will influence choice of appropriate inventory descriptors. Specific goals and objectives may vary substantially among particular projects and programs. Absence of a goal, objective, or descriptor does not necessarily imply that the missing item is not relevant to the type of infrastructure being considered. The four major classes shown are based on the work of the NCPWI; other infrastructure modes could be included. The table serves as an example and should be revised to suit specific applications of the framework.

Effectiveness, or the ability of the system to provide the services the community expects, is generally described by (1) capacity and delivery of services, (2) quality of services delivered, (3) the system's compliance with regulatory concerns, and (4) the system's broad impact on the community. Each of these four primary dimensions of effectiveness encompasses an extensive and varied set of specific indicators and measures. The committee has suggested what some of those specific measures might be, but the actual measures used will depend on the specific context of the decisions to be made.

The final column, other community concerns or impacts, includes many items that fall outside the scope of the immediate requirements placed on the system, items that economists often refer to as "externalities." Over time there is a tendency for public values to shift, bringing these externalities into the mainstream of decision making. For example, dean air was taken for granted in the planning and management of highways until motor-vehicle pollution emissions were found to be an important contributor to declining air quality in urban regions. Rising public concerns led eventually to passage of federal legislation that imposed emissions restrictions on vehicles, set ambient air quality standards, and

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE ES-4 Framework and Measures of System Effectiveness*

Inventory (*Table 4-1*)	*Dimensions, Indicators, and Example Measures of Effectiveness*[*]			
Public works element, type	Service Delivery/Capacity (engineering specifications, technical output, quantity delivered; supply and consumption)	Quality of Service of Users (customer acceptance, satisfaction, willingness to pay)	Regulatory Concerns	Community Concerns, Community-wide Impact, Externalities
Generic: all elements or types	• Output (per unit time, e.g., hour, day, month; peak, average, minimum) • Technical productivity (output per unit input) • Utilization (per unit time, e.g., hour, day, month; peak, average, minimum) • Access/coverage (e.g., faction of population served) • Contingency	• Consumer Safety • Satisfaction • Availability on demand/ congestion • Environmental/ecological quality	• Service-related (i.e., pricing) • External (i.e., Clean Air Act)	• Economic impact • Public health & safety • Social well-being (quality of life) • Environmental residuals and byproducts (i.e., pollution & other NEPA impacts) • National security • Equity (i.e., distribution of costs, benefits, consequences)

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness*[*]			
Transportation Systems	• Output - Vehicle movements - Seat-miles - Route closures (hours), breakdowns • Technical productivity - Seat-miles per labor hour - Seat-miles per route mile - Operating cost per passenger - Passenger-miles per seat mile - Percent of bridges with weight restriction - Percent of vehicles not meeting latest pollution, noise emission targets - Average fuel consumption • Utilization - Mode split - Trip purpose distribution - Number of trips - Passenger-miles • Access/coverage - By jurisdiction - Special segments (e.g., mobility impaired) • Contingency - Emergency response capability - Severe weather response experience	• Consumer Safety - Accident events - Value of losses - Fatalities per capita total, or per annual user • Satisfaction - Level of service - Average speed - Space per passenger - On-time service - Fare, cost to use - Ride quality • Availability on demand - Average wait time - Route closures (hours), breakdowns • Environmental/ecological quality - Air pollution emissions rates - Road treatment chemical pollution (e.g., winter salt)	• Service-related - Access to international routes - Vehicle inspection effectiveness - Speed limits • External - Noise control restrictions - Air pollution emissions restrictions • Fleet fuel efficiency standards	• Economic impact - Person-hours of travel time • Transport industry sale - Access-based property value increases • Public health & safety - Pedestrian accident rate • Social well-being - Neighborhood disruption - Construction/repair disruptions • Residuals and other NEPA impacts - Construction wastes - Road salt in stormwater runoff • National security - Bridge heights adequate for military vehicles • Equity - Income versus mode split - Service to minority communities

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness**			
Water Supply	• Output - Gallons treated - Storage volume - Maximum head (pressure) • Technical productivity - Cost per gallon - Leakage/loss rate - Removable trace contaminants • Utilization - Per capita consumption • Access/coverage - Supply area - Recycling volumes • Contingency - Fire delivery pressure - Reserve storage	• Consumer safety - Main breaks - Fire protection service coverage - Disease outbreak incidents • Satisfaction - Water taste, color • Availability on demand - Reservoir capacity versus demand (days) - Service outages, restrictions • Environmental/ ecological quality - Low flow restrictions	• Service-related - Conformance to Safe Drinking Water Act standards • External - Heavy metals in sludge - Water drawn from wetlands sources	• Economic impact - Water use restrictions • Public Health & Safety - Worker accident rates • Social well-being - Houses with indoor plumbing - Public drinking fountains • Residuals & other NEPA impacts - Treatment of chemical waste • Construction/repair disruptions • National security - Protection from terrorist acts • Equity - Catchment area versus service area b. Low income houses with indoor plumbing

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness*[*]			
Wastewater (Sewage and stormwater)	• Output - Gallons treated - Stormwater storage volume • Technical productivity - Cost per gallon - COD/BOD reduction - Sludge load - Percent of heavy metals, other toxics removed - Sewered area per mile of main • Utilization - Per capita sewage treated • Access/coverage - Sewered area • Contingency - Capability to respond to toxics overload - Overflow frequency (combined systems)	• Consumer Safety - Main breaks - Infiltration to water supply - Compliance with NPDES requirements • Satisfaction - Back-up, retention, overflow during peak load periods. - Noxious odor • Availability on demand - Peak capacity limitations - Overflow incidence • Environmental/ecological quality - Wetlands habitats threatened by runoff - Receiving waters quality	• Service-related - Effluent restrictions • External - Endangered Species Act restrictions	• Economic impact - Wastewater treatment requirements (e.g., for factories) • Public health & safety - Disease outbreak incidents - Worker accident rates • Social well-being - Homes on system • Residuals & other NEPA impacts - Construction/repair disruptions - Landfill volumes - Hazardous by-products - Odor in plant area • National security • Equity - Distribution of flooding by neighborhoods - Disposal impact area versus service area

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness*[*]			
Municipal Waste	• Output - Tons collectable - Special waste collection, disposal potential (e.g., medical, nuclear) • Technical productivity - Cost per ton - Tons collected per truck - Ton-miles haul per ton • Utilization - Tons collected, per capita or per job • Access/coverage - Collection area - Industrial customers • Contingency - Alternatives in event of pollution regulatory change	• Consumer safely - Hazardous waste control • Satisfaction - Community perception of risk - Storage space required per household, employee • Availability on demand - Disposal reserve capacity to accommodate growth - Disposal restrictions • Environmental/ecological quality - Air, water pollution emissions	• Service-related - Recycling requirements - Incinerator moritoria • External - Clean Air Act restrictions	• Economic impact - Disposal restrictions - Resource recovery - Landfill areas with restricted development potential • Public health & safety - Worker accident rates • Social well-being - Street cleanliness • Residuals & other NEPA impacts - Incinerator emissions - Wetlands affected - Population exposed to disposal site effects • National security • Equity - People adjacent to disposal sites, haul routes

[*] Dimensions and measures may be added or deleted to match local objectives. Absence of measures does not necessarily imply that indicator is less relevant to the type of infrastructure being considered. All measures may be determined at particular reliability levels. The table serves as an example and should be modified to suit specific projects and programs.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

TABLE ES-5 Examples of Measures of System Reliability

Type of indicator, measure	*Example measures*
Deterministic	a. Engineering safety factors b. Percentage contingency allowances c. Risk class ratings
Statistical, probabilistic	d. Confidence limits e. Conditional probabilities (Bayesian statistics) f. Risk functions
Composite (typically deterministic indicators of statistical	g. Demand peak indicators h. Peak-to-capacity ratios i. Return frequency (e.g., floods) j. Fault-tree analysis

TABLE ES-6 Examples of Measures of System Cost

Basic indicator	*Example measures*
1. Investment, replacement, capital, or initial cost	a. Planning and design costs b. Construction costs c. Equity d. Debt
2. Recurrent or O&M cost	a. Operations costs b. Maintenance costs c. Repair and replacement costs d. Depreciation costs e. Depletion costs
3. Timing and source	a. Timing of expenditure b. Discount and interest rates c. Exchange rates and restrictions (e.g., local versus foreign currency) d. Sources of funds, by program (e.g., federal or state, taxing authority) e. Service life

generally had significant implications for infrastructure planning, implementation, and evaluation.

Reliability, a recognition of the various uncertainties inherent in infrastructure's services, is the likelihood that infrastructure effectiveness will be maintained over an extended period of time or the probability that service will be available at least at specified levels throughout the design life of the infrastructure system. Each measure of effectiveness can in principle be characterized by statistical indicators that measure the system's

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

reliability with respect to that particular element of effectiveness. However, other indicators such as engineering safety factors, anticipated frequencies of recurrence (e.g., the "100-year flood"), or bases for identifying peak load (e.g., the "100th busiest hour") may be equally useful as measures of reliability.

The basic elements of cost are initial construction or replacement cost (also called investment cost) and the recurring expenditures for operations and maintenance that will be required throughout the facility's or system's service life. While total costs (measured in dollars) are always important, the questions of when money is spent, by whom, and from what budgets often have a great impact on the decisions that are ultimately made.

Infrastructure systems evolve through an ongoing cycle of planning, implementation (e.g., construction or rule-making), and evaluation of in-service operations. Performance measurement is an important aid to decision making at each of these three stages, but the measures may differ from one stage to the next.

Different institutional entities interact in a number of ways to influence decisions about infrastructure. Government bodies may enact laws and impose regulatory standards or planning and coordination requirements. Private entities may impose such requirements and standards as well, for example, when banks or insurance companies insist that borrowers meet certain conditions before financing is provided for infrastructure. Entities that control money wield great power in all stages of decision making. Negotiation among stakeholders often is the decisive final basis for decision. In all these cases, performance assessment can provide an orderly and ultimately defensible basis for decision making.

IMPROVING INFRASTRUCTURE PERFORMANCE

Recognizing the multiple dimensions of performance and the different points of view of stakeholders makes it clear that there is seldom a single, optimal solution for infrastructure problems. Improving infrastructure performance involves finding solutions that are the best that stakeholders can agree on at the time. There are technical and judgmental challenges in presenting the feasible tradeoffs among various aspects of performance, and techniques have been developed to help meet these challenges. Multiple criteria decision making, risk analysis, and discounted cash flow analysis are examples of such techniques. A key to the successful application of a multiple objective analysis lies in early and frequent involvement of all stakeholders.

Inevitably and appropriately, assessing performance adequacy is a matter of value judgments. The procedures used to reach a judgment will have ethical implications, which may become significant for important

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

decisions. Developers of new infrastructure and regulatory agencies may arouse public resistance if these implications are not effectively addressed.

While different levels of government may have well-defined roles in the planning, development, operation, maintenance, and financing of urban infrastructure systems, the systems themselves do not respect jurisdictional boundaries. Similarly, there are a variety of issues that create interrelationships across infrastructure modes that can only be addressed through cooperation among the agencies responsible for each mode (e.g., transportation, water, wastewater, and solid waste). Improving infrastructure performance will require significant cooperation across jurisdictions and across agencies.

In many areas of the United States, regional agencies, special-purpose authorities and districts, joint power agreements, and other voluntary or legislatively defined arrangements have been used to provide for regional and cooperative approaches. In addition, federal and state legislation for funding infrastructure often requires multijurisdictional cooperation and involvement, as well as broad public involvement, as a condition for funding eligibility. The strength of these arrangements and the degree to which regional approaches are followed and supported vary widely from area to area. As improvements in infrastructure system performance are sought, improving multijurisdictional cooperation is likely to be crucial.

Increasingly powerful and cost-effective computer-based forecasting and simulation methods and new technology for measuring and monitoring system conditions have made more sophisticated approaches to assessing system performance widely available. Remote sensing, real-time monitoring, and network analysis and simulation models provide powerful new capabilities for measuring systemwide conditions and evaluating system changes. These tools will support more meaningful multijurisdictional and multimodal cooperation.

Despite the availability of such new tools, there remain many impediments to infrastructure performance measurement and management. Practitioners and researchers should work together to make further improvements in decision-making methods with multiple stakeholders, performance measures, and functional modes of infrastructure working together as a system. Data collection and management and benchmarking will continue to be needed to build a firm basis for achieving high performance from the nation's infrastructure.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.
Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

1

INTRODUCTION

The nation's water supplies, transportation, wastewater, solid waste, and other infrastructure provide a range of essential services.[1] They facilitate movement of people and goods, provide adequate safe water for drinking and other uses, provide energy where it is needed, remove wastes, and generally support the U.S. economy and quality of life. They are public assets that grow in value, with each generation called on to make its contribution to the legacy. Infrastructure is developed to enhance public health and safety, provide jobs, foster regional economic development, and protect the environment. Improvements in infrastructure technology and management have been responsible for controlling cholera and other diseases epidemic in the last century and for opening vast new opportunities for people to live and work in ways they enjoy. At the same time, new demands for infrastructure services have arisen, for example, to reduce losses from highway accidents, control water pollution from new development, and provide faster travel between distant places. In addition, an increasing awareness has emerged about the broader role of infrastructure in shaping development and the environment. Bridges, bike paths, telecommunications dishes, and electric power transmission lines are ubiquitous across the landscape. They annoy, inspire, educate, and amaze and are elements of infrastructure judged by their aesthetic qualifies as well as their functional capabilities. Infrastructure systems serve the broad purposes identified for public construction by the Roman engineer and architect Marcus Vitruvius Pollio two millennia ago. They should, as he wrote, be carried out with strength, utility, and grace (Adams, 1991).

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Responsibility for these systems is primarily a local matter, with some 80 percent of the annual investment in infrastructure coming from local and state government sources or private enterprises, but the federal government's influence on infrastructure development and management is much greater than its 20 percent share suggests. In addition to the many federal programs that provide funds for such purposes as purchasing public transit buses, building sewage treatment plants, and dredging harbors, other programs set standards for water and air purity, control the nation's airways, monitor public health, and otherwise seek to ensure the safety and efficacy of infrastructure. Yet despite these many programs and regulatory activities, there currently is no integrated federal policy toward infrastructure as a whole, although integration within modes has increased in recent years.

Many people assert that such a policy is needed because government below the federal level is unable to deal effectively with the issues of urban development and infrastructure. More than three-quarters of the nation's population now resides in metropolitan areas, and these urban agglomerations account for a major share of our economic output. Within each metropolitan area, myriad local government bodies hold limited authority and often compete for development and tax revenues. Most state governments must contend with the concerns of rural interests as well as several metropolitan areas or parts of areas that span state borders. Critics claim that sprawling and wasteful use of land, impoverished and decaying inner-city areas, and deterioration of suburban quality of life are among the adverse impacts of this lack of institutional coordination. Others argue, however, that such problems are not new and in any case are the result of factors that extend well beyond the influence of infrastructure.

Whether integrated policy is warranted, the possible content of such policy toward infrastructure, and ways to make federal infrastructure programs generally more effective and efficient, are issues that continue to spark debate. The Federal Infrastructure Strategy (FIS) is a three-year program created to provide the substantive framework for resolving these issues. Originating in the President's fiscal year 1991 budget request, the FIS is an interagency activity directed and administered by the U.S. Army Corps of Engineers (USACE).[2]

SOURCE AND CONDUCT OF THE STUDY

As a part of the FIS program, the USACE requested that the National Research Council (NRC) undertake a study on measuring and improving infrastructure performance. The NRC appointed the Committee on Measuring and Improving Infrastructure Performance to conduct this study.[3] This committee held its first meeting in Washington, D.C., on October 7

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

and 8, 1993. Over the course of the subsequent 10 months, the committee met four more times. To provide practical background for their study, and to explore how concepts of performance are used by decision makers, the committee visited three cities selected to represent typical situations in which performance measures might be used: Baltimore, Maryland; Portland, Oregon; and Minneapolis-St. Paul, Minnesota. During these visits, the committee met with government officials and other knowledgeable professionals in each area to discuss particular projects and the region's infrastructure more generally. This document is a report of the committee's deliberations, findings, and conclusions.

Prior to the committee's first meeting, NRC and USACE staff—together with members of the Commission on Engineering and Technical Systems and its constituent boards and staff and members of other units of the NRC—worked together to prepare a background paper, which became the basis for the study prospectus and the Statement of Work incorporated in the February 16, 1993, contract between the NRC and the USACE. On April 14 and 15, 1993, an initiating colloquium was held in Washington, D.C., to develop a list of key issues related to the definition, measurement, and achievement of appropriate infrastructure performance; to delineate the principal areas to be explored in addressing these issues through subsequent study activities, such as data needs, problems of measurement, problems of institutional structure, and others; and to advise Building Research Board staff on the study's future conduct. Participants in that colloquium are listed in Appendix C.

In support of these several activities, NRC staff conducted bibliographic searches and literature reviews on topics relevant to the study. These topics were sometimes defined broadly to include work in other fields that might be adapted to apply to infrastructure performance. Also included was work done in other past and ongoing NRC studies on infrastructure. Appendix D presents the resulting bibliography.

INFRASTRUCTURE PERFORMANCE AND IMPROVEMENT IN CONTEXT

Although U.S. infrastructure is largely a local matter, federal agencies have broad influence, and it is at the federal level that much of the past decade's discussion of infrastructure policy has occurred. *America in Ruins* (Choate and Walter, 1981) warned that the nation's public facilities were wearing out faster than they were being replaced. Many subsequent reports elaborated on the situation, some suggesting a need for increased U.S. spending on public works infrastructure of as much as 70 percent over recent levels, for repair and upgrading of existing facilities as well as development of new ones.[4] While each such estimate is often disputed,

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

there is broad agreement that federal budgets in the 1990s are unlikely to be a primary source of sharply increased and sustained spending for infrastructure investment. How much spending is reasonable, where the money will come from, and how spending should be allocated are open questions (and well beyond the scope of this study), but the incentives to do better with the assets currently in place are clear. Furthermore, a systematic process for performance assessment at the local level would contribute significantly to improved performance and to the most efficient investments of local, state, and federal funds.

Generally speaking, performance is the carrying out of a task or fulfillment of some promise or claim, and for infrastructure this means enabling movement of goods and people, supplying clean water, disposing of wastes, and providing a variety of other services that support economic and social activities, protect public health and safety, and provide a safe environment and a sustainably high quality of life. Because infrastructure is a means to other ends, the effectiveness, efficiency, and reliability of its contribution to these other ends are ultimately the measures of infrastructure performance. In recent years, the closure of rusted highway bridges, outbreaks of water-borne diseases, and fatal railroad accidents have demonstrated that our views of infrastructure performance can quickly and dramatically change. Seeking to describe and measure infrastructure performance is an attempt to judge how well infrastructure is accomplishing the tasks set for the system or its parts by the society that builds, operates, uses, or is neighbor to that infrastructure.

Because infrastructure is largely a public asset or resource, this judgment is typically made in a public setting. Many people are likely to be involved, and reaching consensus can be difficult. Even when one person has dearly defined responsibility for making investment or operating decisions about some element of infrastructure, that person must be prepared for public scrutiny of his or her premises and conclusions.

This public scrutiny is sometimes intense. While infrastructure serves essential purposes for everyone, public resistance to location of potentially intrusive facilities can dramatically shift the outcomes of public decision making. The negative response in public forums has been sufficiently frequent and intense that new words for some elements of infrastructure have entered the language, and people speak of NIMBYs and LULUs.[5]

The challenge the committee faced in this study was to develop a systematic framework for describing, measuring, and assessing infrastructure performance —a framework that can be used by decision makers. In the end, these decision makers include not only the engineers, architects, urban planners, public administrators, elected officials, and other professionals who develop and operate infrastructure but all the citizens, residents, and neighbors who own, use, and otherwise feel the impact of infrastructure.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Recent legislation and government policy provide a specific context for infrastructure performance assessment. The Government Performance and Results Act of 1993 (P.L. 103-62), characterized by the White House as President Clinton's first step toward "reinventing" government, requires federal agencies to develop strategic plans and annual performance plans and to prepare program performance reports. These plans and reports are intended to hold agencies accountable for achieving program results and generally to enhance the effectiveness of federal programs. In implementing this act, the agencies must adopt "objective" indicators of performance and measures of both "outputs" (e.g., miles of river levees inspected or households relocated in a flood control program) and "outcomes" (e.g., reduced flooding and property losses due to flooding).

Executive Order 12983, signed by President Clinton on January 26, 1994, established "Principles for Federal Infrastructure Investment," calling for infrastructure investment and management consistent with "systematic analysis of expected benefits and costs." Benefits and costs are to be quantified and monetized to the extent practicable, considering both market and non-market factors. The order essentially applies economic benefit-cost analysis, traditionally a project-level tool, to federal infrastructure programs. The order applies to "major programs," which are those with annual budgetary resources exceeding $50 million.

THE STUDY'S FOCUS AND SCOPE

The starting point of this study was the work of the NCPWI, which is embodied in its final report, *Fragile Foundations* (NCPWI, 1988). The committee's scope was limited from the study's start to the specific modes of infrastructure addressed in that report:

- highways;
- mass transit;
- aviation;
- water resources;
- water supply;
- wastewater;
- solid waste; and
- hazardous waste.

For much of its discussion, the committee grouped these modes into four broader categories: (1) transportation, including highways, mass transit, and aviation; (2) water, including water resources and water supply; (3) wastewater (both sanitary sewage and stormwater runoff); and (4) municipal waste, including both solid and hazardous wastes. In addition,

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

the committee often sought to generalize their discussions, to deal with performance of infrastructure as an integrated, multifunctional system.

Other infrastructure modes, such as telecommunications, energy production and distribution, and parks and open space inevitably entered the committee's discussion but are essentially beyond the scope of this report. Many of the principles and recommendations discussed here apply to all infrastructure modes, but their application to these other modes was not explicitly considered.

Infrastructure is built and serves regions on many scales, but the committee focused on issues arising from transportation, water, and waste within urban regions. These metropolitan areas account for more than 75 percent of the current U.S. population.[6] The organizational context of these issues is primarily local governments, multijurisdictional bodies (e.g., regional councils), and states. Many of the issues of urban infrastructure apply as well to interregional infrastructure (e.g., rural highways, water transmission canals, and pipelines), giving the study's results broader relevance; but such topics as rural access, interstate water and waste transfers, the remediation of sites of toxic chemical and nuclear contamination, and national energy policy are beyond the scope of this report.

SEEKING REPRESENTATIVE EXPERIENCE

Seeking to ensure that its recommendations on performance measurement would be most useful, the committee visited three metropolitan areas to explore ways in which local officials currently manage their infrastructure and judge its performance. These visits were designed to supplement the committee's review of literature, which included materials prepared by the American Public Works Association (APWA) and others to assist those responsible for infrastructure management,[7] and committee members' own experience. The committee considered several factors in selecting the three areas for visits.

Some areas offered major projects that were ongoing or recently completed that could provide specific lessons in how decisions are made. Boston's Central Artery and Third Harbor Tunnel, Phoenix's solid waste transfer facility, or Denver's new international airport are among the more widely publicized examples. Some areas, such as cities in the Los Angeles region and along the central Mississippi and Missouri Rivers, were recovering from natural disasters.

Economists and geographers have attempted to develop ways to group the 280 metropolitan regions of the United States into a few major classes based on their mixes of industry and population, their urban form, and their political systems.[8] Some areas seem particularly representative of these classes and might therefore offer easily transferable lessons. The

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

largest, smallest, or otherwise extreme examples of U.S. metropolitan areas were unlikely to be so representative.

Some types of economic activity rely more heavily on infrastructure than others. For example, housing must be linked to systems for supply of clean water, removal of wastes, and transportation of people. Manufacturing generally requires transportation as well, often over longer distances and for bulkier manufacturing inputs and finished products. Banking and other service industries rely more on communications. Understanding of the importance of infrastructure performance might be gained by considering a particular industry within the context of a specific geographic area.

Such considerations led the committee to adopt three principal criteria for proposing places to be visited: (1) the regions should be representative of the nation's diversity of urban regions and not extreme situations, for example, size and population, area of the country and climate, political structure, and economic structure; (2) each case should present a relatively stable situation for assessment, that is, a situation not influenced by major disasters, natural catastrophes, or other unusual events that would have lasting impact on the normally anticipated pattern of economic growth, stasis, or decline in the region; and (3) someone among the study's committee members, staff, or liaison representatives should have substantial knowledge of the area to provide meaningful guidance and direction as a whole. In addition, local government officials and staff should be willing to support the committee's work, for example, by providing background information, briefing committee members, and participating in discussions related to the committee's work in the region. Finally, the number of visits would necessarily be limited by the resources available for this part of the study.

The committee selected three medium-sized cities: Baltimore, Maryland; Portland, Oregon; and Minneapolis-St.Paul, Minnesota (the Twin Cities). The first two were visited to help the committee develop and refine its approach to measuring infrastructure performance. The visit to the Twin Cities was less exploratory, serving as a test of the principles and procedures the committee had previously developed.

PERFORMANCE MEASUREMENT IN PRACTICE

This study focused initially at a project level but was not restricted to that level. While not well defined in professional usage, the term "project" generally implies a specific undertaking with distinct purpose, location, start, and finish. In contrast, programs are typically more general in their definition and give rise to multiple projects. For example, the federal Interstate Highway program provided the major share of funds for construction of the expressways that penetrate and encircle many U.S. urban regions: each such highway may be termed a project.[9]
It is typically at the

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

project level that alternative technologies—for example, for type of pavement or water treatment process—are serious options for decision making.

The infrastructure of a metropolitan area is an assemblage of projects. They are built, operated, used, and maintained by an array of private and public institutions. This study's systemwide approach of looking across infrastructure modes (water, transportation, wastewater, solid wastes) to define performance in an urban region runs counter to the typical institutional structure of infrastructure. This institutional structure currently consists largely of organizations concerned with both programs and projects within a single mode. Critics of the nation's infrastructure management cite this arrangement as an obstacle to improved performance of infrastructure as a whole, saying it deters effective thinking about the interactions and tradeoffs among the various modes.

Infrastructure operations and management nevertheless are often reasonably coordinated at the local level. City government and utility company personnel can meet frequently to minimize the disruption of one mode by another. The public, however, sees many examples of problems. For example, trenches are cut in newly paved streets to allow water line repairs or electric power and telephone lines are accidently severed by sewer construction. On a broader scale, land developers construct new homes that generate traffic for which connecting highways are inadequate and no transit alternatives are available. One local agency may extend water supply to suburbanizing areas while others lack funds to provide sewerage. At state and federal levels, coordination may be even less effective. Overall, institutional structure in metropolitan areas can be crucial to performance, and no single arrangement of responsibility and authority is likely to be best in all situations.

The committee initially felt that its study should accept the current mode-specific institutional structure for infrastructure management as a fixed context within which its recommendations would be made. After discussion the committee agreed that performance improvement can in the short term be achieved only within existing administrative and regulatory structures.

In visits to Baltimore, Portland, and Minneapolis-St. Paul, however, the committee saw that a variety of institutional structures are possible and that change can occur when it is warranted. More important the committee agreed that substantial improvements in many areas may require longer-term institutional change to permit truly multijurisdiction and multimodal infrastructure management. Such management is needed, in turn, if infrastructure systems are to achieve their best performance.

Institutional structure and performance measurement are both multi-level and inextricably linked, from national and regional programs that shape infrastructure (e.g., the interstate highways or river basin development) to particular projects or parts of a facility (e.g., asphalt concrete

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

pavements or flood control levees). Performance at the most detailed level of concern is related ultimately to the higher levels. Decisions made at these various levels have interrelated effects as well, with linkages coming into play through government regulations and standards of practice. The actual design criteria used by designers at the project level, for example, to ensure appropriate skid resistance of a highway's pavement, are not changed from one section of road to the next to optimize the highway's performance, possibly influencing the cost-effectiveness or safety of the larger system. The committee's members were mindful of these various complex linkages in their discussions.

Viewed at all levels, however, infrastructure is a valuable system of assets. The system's performance is defined by how well it serves the objectives of this multilevel—that is, local, state, and national—community. Identifying the objectives, assessing performance, making tradeoffs when objectives conflict, and managing the public's assets to improve infrastructure performance occur through an essentially political process involving multiple stakeholders.

The people who make decisions about infrastructure development and management are typically elected officials and the senior technical administrators in a region—for example, planning directors and public works directors. This latter group must on the one hand advise elected officials and the public on infrastructure and on the other hand direct the development and operations of infrastructure facilities and services. The committee identified these decision makers as the most likely users of this study's results.

For decision makers faced with the challenges of managing infrastructure within such diverse settings, performance measurement is a technical component of the broader task of performance assessment, determining whether infrastructure is meeting the community's objectives. The measurement is an essential first step in effective decision making aimed at achieving improved performance.

The committee's challenge was to develop a workable definition of performance and bases for its measurement wherein broad economic, social, environmental, and possibly even political goals can be translated into specific measures and then into standards usable in making decisions about particular infrastructure facilities and operations. The process and framework for performance measurement should help decision makers understand their options and decide not only what facilities are needed to meet society's demands but also how those facilities may best be developed, operated, and maintained. These decision makers are found at all levels of government and the private sector.

Drawing on their own experience and their observations during this study, the committee members concluded that **there are problems with the way infrastructure performance is measured and managed. Most**

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

current measurement efforts are undertaken because they are mandated by federal or state governments or as an ad hoc response to a perceived problem or the demands of an impending short-term project. The interactions among infrastructure elements, for example, transportation and wastewater, are seldom explicitly considered and are even less frequently reflected in management policy. Despite the importance of measurement, current practices of measuring comprehensive system performance are generally inadequate to provide a comprehensive basis for effective decision making.

The recent changes in federal government policy are intended to improve performance assessment. This study seeks to contribute to this effort in three ways: (1) by developing a process and framework that take a multimodal and systemwide perspective, (2) by limiting assessment to social objectives, and (3) by dealing explicitly with the multiple decision makers and levels of governments involved in infrastructure management.

THE REPORT'S STRUCTURE

Together with this introduction, Chapter 2 presents the committee's basic definitions of infrastructure performance and how its measurement may be used in managing a metropolitan area's infrastructure. Chapters 3 and 4 present the committee's recommended process and framework for measurement and for using performance measures in decision making. Chapter 4 in particular recommends the dimensions and broad measures of infrastructure performance and suggests examples of specific indicators for the four broad categories of infrastructure included within the study's primary focus.

Chapter 5 deals with a number of considerations related to implementing performance-based infrastructure management in a metropolitan area. Chapter 6 summarizes the committee's principal findings and conclusions (indicated in boldface type throughout the report) and its recommendations for measuring and improving infrastructure performance. These chapters outline the actions to be taken to put the committee's performance measurement framework into practice.

NOTES

1. The precise meaning and scope of the term "infrastructure" continue to be the subject of discussion (e.g., see NRC 1987, 1993). The committee responsible for this report agreed with earlier NRC studies that "infrastructure" necessarily encompasses both facilities and their operations. Refer to Appendix E. As explained, this report's scope is for the most part limited to the range of modes covered in the work of the National Council on Public Works Improvement (NCPWI, 1988).

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

2. For a full discussion of the FIS program, refer to Framing the Dialogue (USACE, 1993).

3. The Statement of Task given the committee is presented in Appendix A. Brief biographical sketches of the committee's members and staff are in Appendix B.

4. As already noted, "infrastructure" encompasses a broad range of facilities and services provided by government and the private sector. The term is often used interchangeably with the narrower "public works" or "public works infrastructure," which imply government activity, but the private sector plays an important and sometimes dominant role. Refer to Appendix E for definitions of terms the committee uses in this report.

5. These terms, respectively signifying "Not In My Backyard" and "Locally Unwanted Land Use," are joined by other less widely used acronyms, for example, NOTE ("Not Over There Either!") and NIMTOO ("Not In My Term of Office!")

6. While researchers and the U.S. Bureau of the Census strive to develop precise definitions of "urban," "metropolitan," and related terms, unless otherwise noted they are in this study used imprecisely and interchangeably to refer to a city and its subcenters and suburbs.

7. For example, such guidance manuals as *Public Works Management Practices* (APWA, 1991) and the U.S. Army Corps of Engineers' *National Economic Development Procedures Manual* (USACE, 1991).

8. For example, see Berry and Gillard, 1977.

9. Whether a particular highway or other infrastructure element is one or several projects is often a matter of context and open to some interpretation.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

2

INFRASTRUCTURE PERFORMANCE AND ITS MEASUREMENT

The word "performance" is widely used in many contexts. When applied to infrastructure, the word generally is understood to mean supplying clean water, moving people and goods from one point to another, or removing wastes, but judging infrastructure performance is a complex matter. What are the characteristics of "clean" water? Suppose a water system delivers water that is accepted by the community as "clean," but the supply is less than consumers would like to have at certain times of day. Suppose again that the system can be adjusted to increase volumes, but the cost is high. What if developing new supplies means damming a stream to build a reservoir?

Facing such questions and contingencies, providers, users, owners, and neighbors of the facilities and services of infrastructure typically differ—often widely—in their views of the relative importance of any single aspect of infrastructure. As a multifunctional system, infrastructure provides a range of specific services that differ substantially from one mode to another (e.g., transportation, wastewater management). Although costs, social and economic benefits, reliability, environmental consequences, and other factors are widely recognized as important aspects, there is no single generally accepted list, framework, or method for comprehensively describing infrastructure performance.

In developing its 1988 report, the NCPWI reviewed "various proxy measures for factors that influence the demand for and supply of public works services..." but found that "none of the individual measures... gives a clear or convincing picture of the state of the nation's infrastructure

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

because they measure only certain aspects of demand or supply" (NCPWI, 1988). The NCPWI then commissioned new studies to undertake "an assessment of the performance of the nation's infrastructure," which measured performance in terms of "four measures: physical assets, product delivery, quality of service, and cost-effectiveness." Table 2-1 presents "illustrative measures" the NCPWI cited for physical assets, product delivery, and quality of service. The NCPWI report only hints, however, at a clear definition for the term "performance," saying simply that "demand for and supply of public works services jointly determine performance levels and the quality of services provided" (NCPWI, 1988).

A necessary early step in this study therefore was adopting an explicit definition of performance. The committee agreed that no single indicator or index is likely to be a sufficient practical measure of infrastructure performance. Table 2-1 thus became the point of departure for the committee's efforts, and in key aspects the committee diverged substantially from the NCPWI's earlier work.

THE BASIC CONCEPT OF PERFORMANCE

If "performance" is, as a dictionary defines it, the execution of a task or fulfillment of a promise or claim, then infrastructure performance is the accomplishment of tasks set for the system or its parts by the society that builds, operates, uses, or is neighbor to that infrastructure. In short, the bases for measuring infrastructure performance are defined by the broad community. As has already been noted, this community includes national-and state-level as well as local perspectives. As a consequence, there generally may be many measures of performance, and they may vary from place to place.

The tasks the community wants its infrastructure to accomplish initially have to do with moving goods and people or providing clean water, but society sets broader tasks as well. Infrastructure provides jobs to the people who construct, operate, and maintain its facilities and services. By providing more or better services in some regions or to some social groups, infrastructure fosters differential patterns of income, economic opportunity, and growth. As a market and test bed for new technologies, infrastructure enhances or retards technological innovation and the resulting growth of economic productivity. The public objection that its facilities sometimes engender is evidence that infrastructure is failing to meet social, cultural, or aesthetic purposes. The effectiveness of infrastructure as a public investment serving these broader ends also is an essential aspect of infrastructure performance.[1]

It would be tempting to suppose that a simple indicator of infrastructure performance could be devised, a single index of how well the system

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 2-1 Illustrative Measures of Infrastructure Performance, as presented by the National Council on Public Works Improvement (Source: NCPWI, 1988)

Public Works	*Physical Assets*	*Service Delivery*	*Quality of Service to Users*
Highways	Lane-miles Number of bridges Vehicle registration Fleet size	Passenger miles Vehicle miles Ton-miles	Congestion or travel time Pavement condition Volume/Capacity ratio Accident rates Population with easy access to freeways
Airports	Number of aircraft Commercial seat-miles Number and type of airports	Passenger miles Enplanements Aircraft movements	Number and length of delays Accident rates Near miss rates Population with easy access
Transit	Number of buses Miles of heavy rail Subway seat-miles Bus miles	Passenger miles Percent of work trips Transit trips	Average delays Breakdown frequency Population with easy access Elderly/handicapped access Crowding: passenger miles per seat-mile
Water Supply	Water production capacity Number of water facilities Miles of water main	Compliance with MCLs Reserve capacity Finished water production Fraction of population served	Water shortages Rate of water main breaks Incidence of waterborne disease Finished water purity Loss ratios
Wastewater Treatment	Capacity (mgd) Number of plants Miles of sewer	Compliance rate Reserve capacity Infiltration/inflow Volume treated Fraction of population served	Compliance with designated stream uses (local) Sewage treatment plant downtime Sewer moratoria

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Public Works	*Physical Assets*	*Service Delivery*	*Quality of Service to Users*
Water Resources	Number of ports, waterways Reservoir storage capacity Number of dams Miles of levees, dikes	Cargo ton-miles Recreation days Flood protected acreage Irrigated acreage Kwh hydropower produced	Shipping delays Dam failure rates Power loss rate Value of irrigated agricultural product Value of flood damages averted
Solid Waste	Landfill capacity Incinerator capacity Number of solid waste trucks	Tons of trash collected Tons landfilled Tons incinerated	Collection service interruptions Facility downtime Rate of groundwater contamination

is meeting objectives. However, for the many reasons already cited the committee found that **no adequate, single measure of performance has been identified, nor should there be an expectation that one will emerge. Infrastructure systems are built and operated to meet basic social needs, but those needs are varied and complex. Many people, acting individually and in groups, will have objectives for what infrastructure should do. These stakeholders, at local, state, national, and even international levels, will make their own judgments about whether their objectives are being met. Infrastructure performance must be measured in the context of social objectives and the multiplicity of stakeholders who use and are affected by the infrastructure system.**

Making infrastructure effective in achieving its objectives requires money, land, energy, and other resources. These costs are incurred in planning, construction, operation, maintenance, and sometimes demolition of facilities. There are costs of using the facilities to provide services, of monitoring and regulating the safety and environmental consequences of these activities, and of mitigating adverse impacts of infrastructure. These costs are incurred and paid at different times and places, by different agencies and groups (e.g., users, neighbors, taxpayers), and in nonmonetary and monetary terms. The relationship of these various costs to infrastructure's effectiveness in achieving its tasks is central to the definition of performance.

This relationship of effectiveness and costs exists in an uncertain world. In the best of times, there are limits to the degree to which these relationships can be accurately measured and related to one another. In the worst of times, storms, accidents, and sudden failures of materials and equip

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

ment drastically alter these relationships. Long gestation periods and service lives mean that costs of facilities may change and levels of usage may differ dramatically from early expectations. Nevertheless, despite the general uncertainty that underlies infrastructure's ability to provide its services, society expects reliable service. Reliability—the likelihood that infrastructure effectiveness will be maintained over an extended period of time—is another component of performance.

Infrastructure performance is the degree to which infrastructure provides the services that the community expects of that infrastructure, and communities may choose to measure performance in terms of specific indicators reflecting their own objectives. The committee concluded that these indicators generally fall into three broad categories, measuring performance as a function of *effectiveness, reliability*, and *cost*. Infrastructure that reliably meets or exceeds broad community expectations, at an acceptably low cost, is performing well. Indicators of these three principal dimensions of performance are considered in detail in Chapter 5.

PERFORMANCE COMPARED WITH OTHER CONCEPTS: NEED, DEMAND, AND BENEFITS

As the committee defines it, performance is related to other concepts used in infrastructure management and decision making. One such concept is "need." The term and its underlying engineering concepts appear widely in public works policy analysis, especially as a basis for determining appropriate levels and allocation of state highway construction monies. A congressional advisory committee defined need "in terms of the investment required to construct, reconstruct, rehabilitate, or repair capital facilities so they may provide a desired level of service, given expected patterns of growth and development" (U.S. Congress Joint Economic Committee, 1984). If forecasts of future highway usage show that the present system of highways is likely to become very congested, the "need" for new highway capacity is inferred and becomes the basis for planning new construction.

Service standards that define the "desired level of service" are an important determinant of need. The advisory committee concluded that a clear understanding of need and the influence of standards on needs assessment was lacking on a national scale. Infrastructure investment needs projections in some states were found by the advisory committee to be "quite speculative," sometimes representing little more than "wish lists" of the agencies responsible for construction. The advisory committee recommended, among other things, that a study be made of economic, social, and environmental relevance of diverse standards governing the nation's infrastructure construction.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

NCPWI noted the shortcomings of engineering "need." Because the link between service standards and costs is obscured when need is calculated, the NCPWI concluded that the concept is a faulty basis for decision making. The study committee agreed with that assessment.

The NCPWI then considered whether the economist's concept of "demand," useful in describing consumers' behavior, applies well to infrastructure. "Demand" reflects the relationship between levels of service and the price that recipients of that service must pay. As the price gets higher, the demand for a particular level of service—that is, the number of people willing to pay—generally declines. Demand may potentially be greater than available supply when prices are below what people are able and willing to pay.

While many of infrastructure's services might be priced as though they were being offered in an open market, such pricing rarely occurs. Failure to charge for the use of clean air and water (and other so-called "free goods"), inability to restrict access to services, giving some users a "free ride," and the use of general taxes rather than user fees to finance facility construction and operations are among the many factors that distort the relationships between prices and levels of service.[2] For such reasons, the NCPWI concluded that performance is determined jointly by demand and supply. The study committee endorses that conclusion.

The committee's definition of performance is most closely allied with principles of cost-effectiveness analysis. As is the case with cost-effectiveness analysis, the scope of performance assessment as defined in this study is limited to the objectives set for the system in question, that is, the tasks that infrastructure is to perform.

Infrastructure may have other benefits or adverse impacts that go beyond the immediate concerns of transportation, water supply, or waste removal. These consequences are often long term, sometimes unintended, and frequently extend far beyond infrastructure's facilities. Urban highways are said by some people to have been responsible for urban sprawl and weakening of the sense of community needed to sustain older residential areas. Extensions of trunk sewers and water supplies are similarly credited with enabling suburban growth in previously undeveloped areas and with destruction of wildlife habitat. **The committee found that such impacts become concerns in performance assessment when community expectations recognize them as results to be sought or avoided. They then become part of the performance assessment process and subsequent decision making.** For example, federal legislation (e.g., the Clean Air Act) mandates that transportation systems reduce their emissions of carbon monoxide and other air pollutants. Passage of that law effectively converted an often neglected environmental impact into a major component of performance. Unpolluted air, formerly an economic "externality," became a measure of how well the infrastructure is doing its

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

job. Similarly, federal dean water requirements have added dramatically to the number of pollutants to be considered in determining whether a water system's performance is adequate.

THE VARIETY OF STAKEHOLDERS

The committee's concept of performance depends on the composition of the "community" associated with the infrastructure. Many individuals and entities have a stake in infrastructure's performance.

At a minimum, there is the distinction between providers of infrastructure services and users. Providers include individuals, private firms, government agencies, and regulated or other public-private entities that own, design, build, operate, maintain, and deliver infrastructure's services. Users are individuals or corporate entities. Sometimes the distinction is difficult to make or depends on context. For example, the driver of a transit bus and the agency or company that operates the bus fleet are users of the road at the same time that they are providers of services to people seeking transportation.

Those who are not providers or are not directly served by infrastructure but who nonetheless have a stake in its performance may be termed "non-users." All residents of a metropolitan area, for example, are exposed to the air pollution originating from highway vehicles. The owners and drivers of those vehicles are exposed as well but may have a different perspective on pollution control strategies than would be held by their transit-riding neighbors.

Then there is the distinction of levels at which infrastructure is viewed, from the individual or household to the national or international scale. Political entities, for example, city or county, state, province, or nation, can serve as a convenient designation for an increasingly broad perspective, and for some aspects of infrastructure these entities have functional significance. For example, decisions about highway construction and electric power regulation are made largely at state levels, while water supplies and solid waste processing are primarily the concern of local governments. National and international concerns arise as well, for example, when state or local actions restrict interstate commerce, violate national standards, or influence activities covered by treaty.

Regions defined on other bases, however, have importance for infrastructure that at least equals and often exceeds that of political divisions. Metropolitan areas, for example, are identified by the spread of their populations across the land, influenced but seldom limited by political boundaries. River and stream drainage basins are the natural bases for thinking about wastewater management. Neighborhoods, historic districts, and other socially or economically defined areas may also have a stake in infrastructure performance.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

DIMENSIONS OF EFFECTIVENESS

The several objectives that stakeholders set for the infrastructure system each will have one or more distinct dimensions or elements. For example, an objective of transportation infrastructure may be to facilitate mobility in an area. Movement of people (e.g., going to work or school) and goods (e.g., deliveries to homes and stores in the area) are dimensions of how well the broader objective is being met.

Each such dimension[3] should be distinguished as a single aspect of effectiveness (and hence of performance as well) that can be discussed and measured with minimal reference to other aspects, for example, traffic congestion on a highway versus the stormwater runoff from that highway. In principle the links between each objective and one or more dimensions of effectiveness should be readily apparent and can be visualized as a graph such as that illustrated in Figure 2-1.

Each dimension will in turn have associated with it one or more indicators or measures of effectiveness—signs, symbols, or statistics (typically numerical) that people understand to convey information about how well infrastructure is accomplishing its tasks. These measures may be based on some generally used scale (e.g., volume of water or traffic) or relative to a benchmark (e.g., observed throughput as a fraction of theoretical maximum throughput).

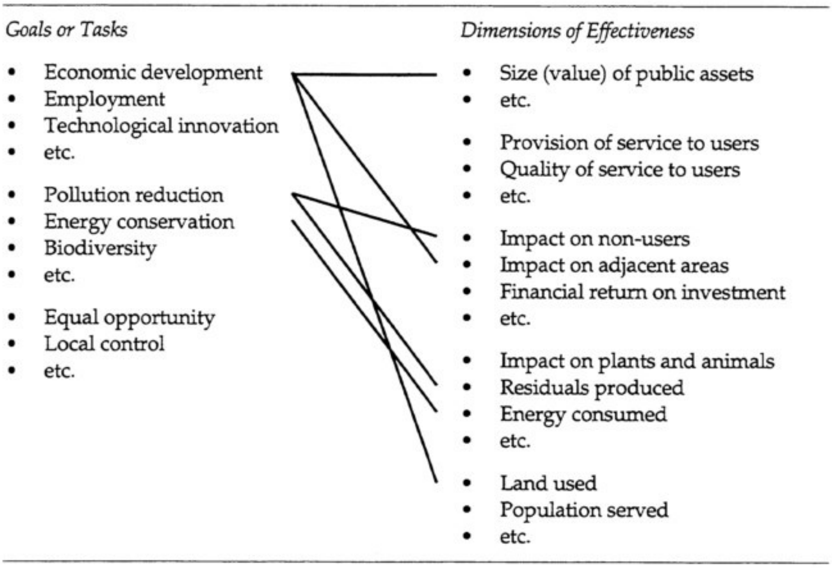


FIGURE 2-1 Dimensions of effectiveness link to objectives infrastructure is to achieve.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Because the objectives set for infrastructure may change from time to time and place to place, the dimensions of effectiveness may change as well. In medieval Europe, for example, rubbish and other wastes were often dumped just outside the city with an expectation only that the height of the mound should not enable attackers to easily scale the city's walls. Today other dimensions of infrastructure effectiveness are important, for example, when distant incinerators and landfills are expected to accommodate the wastes but not emit noxious fumes or infiltrate groundwater.

As discussed in Chapter 3, the process of engaging stakeholders in selecting a comprehensive, appropriate, and operational set of measures of infrastructure effectiveness is for many purposes the most important task in performance measurement. Understanding the logical relationship among objectives, dimensions, and measures of effectiveness is helpful in judging why one or another measure may be appropriate, but it is the measures alone that people will use to assess effectiveness and performance. The committee recommends the framework of measures presented in Chapter 4.

DETERMINING WHETHER PERFORMANCE IS "GOOD"

Because of the multitude of measures describing performance and the different points of view of stakeholders, judging whether performance in a particular situation is "good" or "adequate" may not be easy. Issues of scale and aggregation influence the assessment. For example, infrastructure is expected to provide its various services reliably for long periods of time, but there is always a chance that service will be interrupted. Interruptions sometimes occur due to structural failures, unusually high usage, required maintenance, or other causes, but a certain degree of redundancy and flexibility in the system can allow performance to remain satisfactory, at least when viewed on a broad scale. The people directly exposed to local disruptions, however, are likely to be less than fully satisfied, even if they acknowledge that some interruptions of service are in principle acceptable.

Similarly, infrastructure services for any one user may be disruptive to the services others receive. In an airport passenger terminal, for example, the arrival or departure of each flight potentially will interfere with the flow of passengers and baggage of other flights. Each airline and passenger served seeks good quality service but may suffer delays, inconvenience, or monetary costs because others seek service as well. Performance of the terminal as a whole will generally differ from what the individual user experiences.

The committee noted that many people agree that infrastructure improvements have an impact on economic development and that disparate levels of investment in infrastructure can cause disparate rates or levels of development in cities and communities. Communities accept that without adequate service they will suffer in comparison (or competition) with those that have better

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

infrastructure. However, because infrastructure development typically draws on broad sources of funding, central issues in many decisions about infrastructure relate to the questions of who benefits and who pays. These questions arise over the immediate and longer terms and within the jurisdictions where facilities are located and managed as opposed to the broader region where the infrastructure's impacts are felt. The questions concern both intermodal (e.g., water and transport) and intermedia (e.g., air or water pollution) interactions.

Many of the resources that infrastructure uses or influences—for example, air, water, open space—are traditionally thought of as what economists term free goods, for which there is no distinct cost.[4] Concerns about environmental impacts and limitations on consumable resources have motivated increasing interest in establishing the bases for valuing these free goods, and these values shift the performance assessment even when they are not included as measures of performance. [5]

The committee also noted that despite the agreement on infrastructure's importance, the judgment of what levels of performance are "good" or "appropriate" may be defined somewhat differently within the context of the specific institutional, technical, social, political, and economic make up of a region. Sometimes decisions are based primarily on whether federal funds are available. In particular, political jurisdictions or single-mode institutions (e.g., departments of transportation, power authorities) with adequate funds can develop projects while others cannot, regardless of whether arguments might have been made for different priorities at regional or national levels. Some committee members observed that one result may be the development of "excess" capacity in parts of the infrastructure system. Infrastructure users may experience this "excess" capacity as a high level of service, while the analyst might conclude that users are being effectively subsidized to use the infrastructure's services at charges lower than full cost. This may not be "good" performance.

The committee observed the distinction often made between infrastructure services that "must" be provided and what could be delivered if one chose to commit the resources. With water supply, for example, a community may have water that is basically healthful and meets requirements of the Clean Water Act. Nevertheless, some people may not like the taste or for other reasons choose to purchase bottled water. The choice is available to those who can afford the higher cost but does not indicate whether the system's performance is or is not "good."

BASES FOR JUDGING GOOD PERFORMANCE

The committee observed that when such judgments are to be made there is potentially some tension between public perception and opinion on the one hand and infrastructure professionals acting as experts on the

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

other. There is an analogy in public health: inoculations and other preventive actions are available to protect against a variety of conditions, but people often seem unwilling to be inoculated. Sometimes education enhances willingness, and sometimes action is required by statute. A balance is struck in public policy among the various costs and risks as they are perceived by the experts and the public.

Over time this balance can change and does: public issues evolve and attitudes shift; new information becomes available and technology advances. Such changes have potentially strong impact on what services infrastructure is expected to provide. A system that seemed optimal when it was designed and implemented may become obsolete. Actions that one generation thought were a good idea may be seen differently by a new generation.[6]

The committee found generally that there are few benchmarks or norms of "good" performance that apply to infrastructure as a system, or even that apply comprehensively to all aspects of performance of any one type of infrastructure. Sometimes decisions are based on nothing more than whether the public has complained. Decision makers, however, often seek guidance as to what are acceptable and achievable levels of performance in particular contexts.

Decision makers seek this guidance for decisions that span a wide range of scope and detail. At one level, decisions are made about whether to make major investments in infrastructure development and operations, for example, in constructing a new incinerator with new combustion and air pollution emissions technology. At another level, the decisions concern design and operations details such as the reconstruction of street pavement or the scheduling of trash collections.

Because infrastructure is intended at the higher level to support economic and social activity without adverse environmental consequences, performance ultimately has something to do with the outcomes from its use, for example, regional economic growth and quality of life. However, attempting to quantify the link between infrastructure investments and operations on the one hand and these outcomes on the other hand is difficult, uncertain, and likely to be controversial. As discussed in chapters 3 and 4, measuring the output and consumption of services—for example, vehicle-miles of travel, gallons of water delivered—without reference to subsequent use of those services and ultimate outcomes does not really measure performance but is an essential step.

The committee found that federal standards and standards-setting procedures are influential in motivating measurement but may not foster "good" performance. Because problems are not the same everywhere, dries are sometimes forced to incur costs meeting standards that are locally less of a concern than other aspects of performance. The Safe Drinking

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Water Act, for example, requires the Environmental Protection Agency (EPA) to issue regulations for a substantial number of chemical contaminants (83 by recent count, with additional contaminants to be added every 5 years). The EPA has actually written regulations for perhaps 30 of those contaminants. Yet in early 1993, newspapers around the country reported on large numbers of illnesses caused by microsporidium bacterial infection of Milwaukee's treatment facilities, a problem not covered by federal regulation. Similarly, the Federal Highway Administration sought in the 1970s to impose a 55-miles-per-hour (mph) speed limit on all interstate highways, citing highway safety statistics and automobile energy consumption benefits as the basis for setting this standard. The uniform maximum speed limit proved unpopular and more difficult to enforce in some areas of the country than others. When the states were given the authority to reestablish their own speed limits, many chose to return to the nominal 70 mph they had previously adopted.

In view of such experience, the committee concluded that **performance overall should be assessed on the basis of multiple measures chosen to reflect the community's objectives. Some performance measures are likely to be location-and situation-specific, but others have broad relevance. In all cases, developing performance benchmarks that reflect the experience of past performance achieved in many communities will yield helpful guides for decision makers.**

DIVERGING FROM THE NCPWI'S FRAMEWORK

The NCPWI's framework for assessing performance, embodied in Table 2-1, was the point of departure for the committee's work, but as the preceding text explains, the committee quickly diverged from this earlier work. The differences between the committee's recommendations, presented in the following chapters, and the NCPWI's work are matters of both concept and detail.

The NCPWI characterized performance in terms of four dimensions: physical assets, service delivery, quality of service to users, and cost-effectiveness.[7] The first three of these were then expanded into the lists of illustrative measures included in their table. The fourth dimension the NCPWI referred to as "economic performance" and suggested that its measures fall into two broad categories: economic efficiency and cost-effectiveness. Economic efficiency of a project or program was said to be "reflected by the excess of its benefits over costs," presumably measured in monetary terms. The NCPWI's report stated that "efficiency is only one goal of public works programs and sometimes it is ignored altogether," for example, when Congress asserted (in the 1972 Clean Water Act, P.L. 92-500) that certain levels of pollution control are to be achieved without regard for

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

cost. Cost-effectiveness was said to provide "simpler measures of services delivered per dollar spent," and was therefore a more generally useful "performance measure."

Within this study committee's framework, the first of the NCPWI's dimensions (physical assets) is not a true dimension of performance, because it has nothing to do with the tasks infrastructure is to perform. In the committee's view, the number of buses or water production capacity of the treatment plant are simply characteristics of the infrastructure, statistics to be recorded when the system is inventoried. Developing this inventory is important and is considered in chapters 3 and 4 but is only a prelude to performance measurement.

The study committee agrees that service delivery and quality of service to users, the second and third of the NCPWI's dimensions, are indeed key dimensions of effectiveness (and therefore of performance). The committee suggests in Chapter 4 that there are others as well.

The committee's inclusion of reliability in their framework addresses a dimension of performance given only passing consideration by the NCPWI. Specific measures included in Table 2-1, such as number and length of (airport) delays and reserve capacity (e.g., water supply), have something to do with uncertainties and interruptions of service but do not represent comprehensive measures of reliability.

The committee agreed that the NCPWI's economic measures have much to do with assessing performance. In this committee's view, however, cost is a dimension of performance, but cost-effectiveness, economic efficiency analysis, and other methods such as multicriteria optimization and nondimensional scaling address tradeoffs among cost and other performance dimensions. Such methods for considering tradeoffs are helpful to decision makers seeking to assess performance and choose among options for improving performance of infrastructure. No one method can be expected to yield a generalized single-number measure of performance as a whole. Performance is essentially and unavoidably multidimensioned.

NOTES

1. Even if public funds are not employed, infrastructure is invariably a public investment because it uses land and other natural and community resources that are valuable and could be used in other ways by the public or reserved for future uses.

2. Such issues, the focus of a vast literature and continuing research by economists interested in consumer theory, public welfare, environmental economics, and related fields, are well beyond the scope of this discussion.

3. Definitions of how the committee uses such terms as "dimension," "measure," and "indicator" are included in the glossary in Appendix E.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

4. Of particular relevance to infrastructure is the low value (i.e., typically no value) typically assigned to the space underneath public fights of way. Some people argue that the uncoordinated location of utilities is a result of this absence of value.

5. Such methods as "hedonic" pricing and contingent valuation use statistical analysis and market analogies to infer a market price for such goods.

6. Some members of the community may view infrastructure actions as the work of particular groups that stand to benefit at the expense of other groups. Proponents of such views have cited evidence, for example, of the racial make up of neighborhoods where solid waste facilities are located as a basis for questioning whether equity criteria of "environmental justice" are being met. These criteria could be among the factors influencing what a community judges to be "good" performance.

7. These were termed performance "measures" in the NCPWI's report, as were the constituent items listed in Table 2-1 (NCPWI, 1988).

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

3

THE PERFORMANCE ASSESSMENT PROCESS

If performance is to be a useful concept of infrastructure decision making, and if its assessment depends so critically on the decision making context, then the assessment process itself should encourage appropriate recognition of both the types of decisions to be made and the particular objectives, vision, and character of the areas the infrastructure serves. This chapter describes the committee's conceptual framework for that assessment process. This is a general process; detailed procedures and the individuals and entities involved will vary from one region to another.

MOTIVATION

The primary motivation for assessing infrastructure performance lies within the context of a larger system of decision making aimed at allocating resources and taking action to pursue the public purpose of infrastructure—that is, to produce desired outcomes. For example, an immediate outcome from building a wastewater treatment facility should be cleaner water within a river where the effluent is released. Over the longer term, the outcomes may extend beyond clean water itself to include improved health of the population using or living around the water system, which in turn represents enhanced quality of life for residents in the area. Outcomes may also extend to the downstream ecology, as seen in increased diversity of aquatic species of plants and animals and other wildlife up the food chain. In addition, the effects of cleaner water may flow downstream to neighboring communities that may be able to use a simpler and less

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

expensive process in providing clean, safe drinking water for their own residents. Seeking such favorable outcomes, avoiding unfavorable ones, and determining what outcomes have been achieved are the principal aims of the assessment process, but these aims should be explicit.

Assessment for its own sake, conducted in isolation from the people served by the systems being assessed and devoid of the values of the local community, is an empty exercise. The assessment process must begin with identification of a problem, demand, or need for assessment, that is, with the question "Why are we doing this?" There are many possible answers, ranging from "We have to" (e.g., to meet federal requirements) to "We want a clearer understanding of how to make our public assets work harder for us" to "We have a strategic vision for our community and want to use infrastructure to help us achieve it."

Regardless of the particular motivation, the performance assessment process is a primary mechanism for the expression of community values and subsequent decision making about infrastructure development and management. It is through this process that objectives for infrastructure are defined, specific measures of performance selected, and judgments made about performance. The process must both encourage communication and facilitate resolution of the conflicts that often arise among the diverse objectives infrastructure is meant to achieve.

THE GENERIC PROCESS

Figure 3-1 illustrates the generic process that assessment should follow. The process effectively begins with a question of whether infrastructure performance is adequate, which implies a problem, demand, or need for something different from the existing system. Formulating the question and beginning to search for answers involves identifying who is involved and how and what their ranges of interests may be. The process then proceeds through describing the infrastructure system and its setting in a way that enables performance to be measured and then making the measurement. A judgment is then made as to whether performance is adequate or might be improved by taking specific actions identified during assessment. The process seldom really ends but rather starts anew with different perspectives developed in the assessment. Data about the system and the values underlying a community's judgments inform all stages of the process, which are described further in the following paragraphs.

Figure 3-2 shows the context of questions that initiate the assessment and the types of answers likely to be given. The questioners may include community and other special-interest groups, elected officials, businesses, individual citizens, and others who use, own, operate, abut, or otherwise have an interest in the outcomes of infrastructure-related actions. These

Copyright © National Academy of Sciences. All rights reserved.

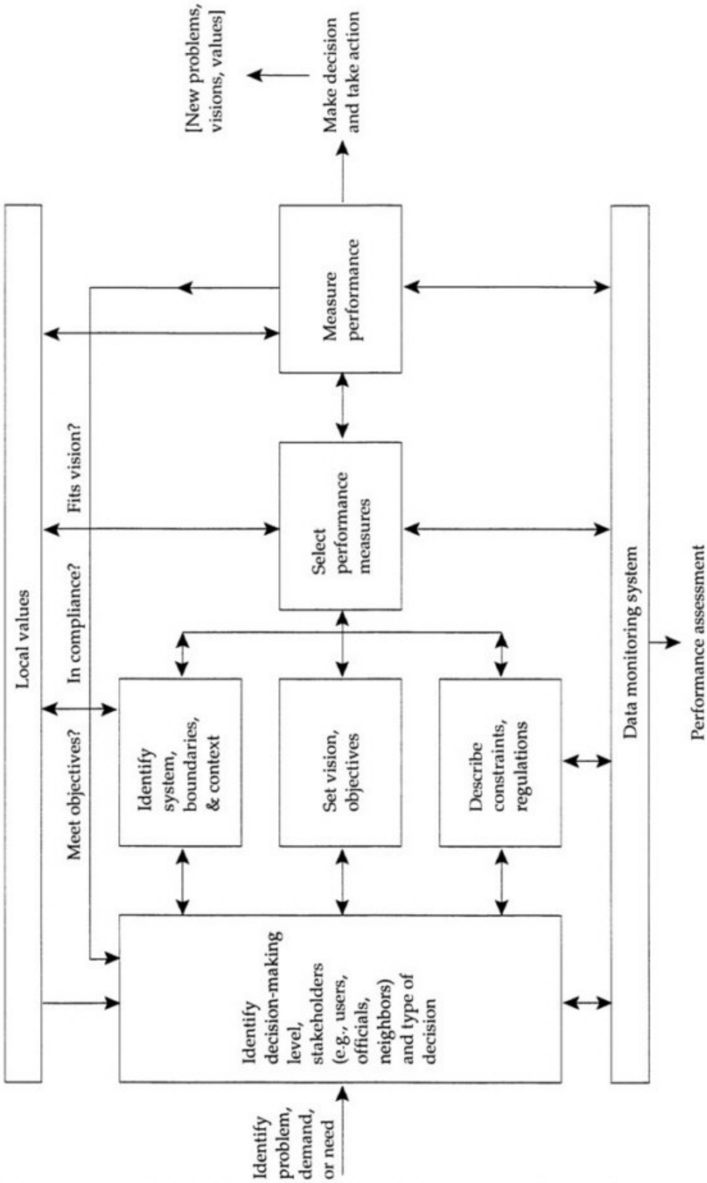


FIGURE 3-1 Performance assessment as a generic process.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Infrastructure					Scope	Other systems and sub-systems		
Other Functional Modes	Municipal Waste	Wastewater (Sewage and Stormwater)	Water Supply	Transport-ation Systems	Stakeholders' Perspectives; Levels of Analysis, Decision, Planning, Control	Land	Other Natural Resources (e.g., air, water)	Other Systems/ Sub-systems (e.g., community groups, historic linkages)
					Global, Multinational			
					Federal, National			
					State, Provincial			
		Committee's primary focus[2]			Regional			
					County, City			
					Community, Neighborhood			
					Household, Individual			

FIGURE 3-2 General context of performance assessment.[1]

[1]Cells contain measures and discussion of performance, appropriate for decisions to be made and referenced to specific systems, location, policies, time, etc. Contents of entire table, in principle, may change when actions affecting infrastructure are taken.

[2]The study focused on infrastructure (and only some functional/modal elements) in urban regions, but unavoidably considered other systems and levels of analysis.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

people are the "stakeholders," and their interests typically extend beyond infrastructure. For example, infrastructure decision makers may consider employment opportunities, land use, community political interests, and a variety of other factors unrelated to infrastructure's performance. As the shaded area of Figure 3-2 indicates, the committee focused its attention primarily on certain elements of infrastructure and within the jurisdictional levels between state and local government, but it inevitably considered a much broader scope of interests.

The first step after the need for performance assessment is established is to dearly identify who the stakeholders are in the decision-making situation that motivates the assessment. The level at which the decision is made (e.g., local or state) and the type of derision (e.g., planning new facilities, determining how to implement a new regulation) will have much to do with who these stakeholders are. However, stakeholders may be found at many levels other than where the decisions are to be made.

In particular, an array of public and private institutions are responsible for building, operating, maintaining, and using the infrastructure of a region to provide services to that region (see Figure 3-3). These provider

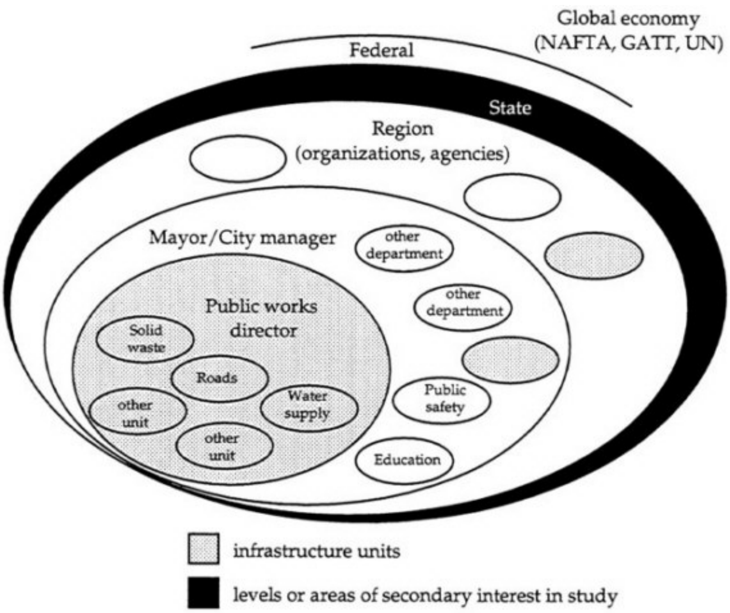


FIGURE 3-3 Stakeholders in performance assessment as seen from the perspective of infrastructure providers.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

institutions (formal and informal, groups and individuals, large and small) are key stakeholders in the region's infrastructure. They prepare and execute master plans, capital budgets, architectural and engineering designs, approvals, purchases, construction, sales, and a range of other activities through which infrastructure evolves. This provider perspective may in principle be mapped out within any of the cells of the matrix shown in Figure 3-2 for a particular region and decision making situation.

Because infrastructure is essentially a local matter, performance assessment should always include the local perspective, even when the decisions of concern are essentially broader. Officials in cities the committee visited pointed out that some federal regulatory and funding programs fail to recognize this need for local perspective in achieving higher infrastructure performance and impose standards uniformly on all areas, regardless of the causes of performance deficiencies or the consequences of inappropriate standards. For example, in Minneapolis advanced treatment of municipal sewage was mandated to relieve a problem of high levels of nitrogen in a local lake that was the receiving body for treatment plant effluent. Studies undertaken by local agency officials demonstrated the source of nitrogen to be agricultural fertilizers.

The next steps in performance assessment deal with identifying the infrastructure system of interest, the boundaries and character of the system and area served, the objectives and vision the community [1] sets for the system, and constraints (e.g., budgets, interagency relationships, jurisdictional) and regulations that may limit the feasibility of actions.

Identifying the system, boundaries, and context often involves use of maps and databases of the types typically maintained by municipal and regional planning agencies, departments of transportation, water utilities, and sewer authorities. These databases increasingly are being stored in computer-based geographical information systems (GISs). Rapidly evolving and sophisticated GIS technology is enhancing the currency of and access to these data, making these technologies valuable resources for performance assessment. This is discussed further in Chapter 4.

The vision and objectives may come gradually and from several sources. A consensus-building community-wide discussion may generate a collective vision of how infrastructure can and should serve the community. Objectives may also come from legislation or other mandates imposed by higher levels of governments. The constraints and regulations may be formally stated in laws, budgets, or official regulations. They may also be informal, as is typically the case with political constraints or the physical constraint that poor soils or steep slopes represent when new construction is being considered.[2]

Selecting and using specific performance measures are crucial tasks that are discussed in depth in Chapter 4. Depending on the problem or

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

demand motivating performance assessment, the selection may involve a substantial amount of public discussion or can be a relatively straightforward adoption of standard planning or engineering practice. Some experts in public decision making practice assert that this process of structuring objectives and measures is more an art than a science (e.g., Keeney, 1988).

While some objectives set for infrastructure may change from one situation to the next, many will remain constant for considerable periods of time. The measures selected for one decision may therefore be useful for subsequent decisions as well, but attention should always be given to confirming that the measures being used suit the situation, as defined by stakeholders, their current objectives, and decisions being made. The types of decisions and their influence on the process are the subjects of later sections of this chapter.

Local values have overarching influence on all steps of the assessment process. Because infrastructure is essentially a local concern, local values should be reflected in the assessment even when the motivation for assessment comes from other levels. Asking stakeholders why they judge particular objectives to be important helps to separate those that are a means to other ends (e.g., reduce automobile travel as a way to reduce automotive air pollution) from those that are related to basic values underlying the decision making situation (e.g., reduce air pollution because air pollution is simply undesirable).

Underlying the entire assessment process is a need for data. **The committee found that in many areas the lack of data is one of the principal obstacles to implementing an effective performance measurement process. A continuing regional data collection system is needed to support performance assessment and enable longer-term performance monitoring**. Many metropolitan areas have in place some basic elements—databases and modeling tools—but have not brought together the information on separate infrastructure modes into a uniform and rapidly accessible system.

As Figure 3-1 illustrates, the assessment process includes feedback to earlier steps. Sometimes work will proceed concurrently on several of the distinctly described steps. At each step, as participants increase their understanding of the problem and their options for solving the problem, reconsideration of earlier steps may be necessary. The process is in a sense progressive, helping people to explore their options, work toward resolving conflicting objectives, and seek a consensus on their preferred course of action, even if that course means no action.

THE RESULTING MEASURES AND THEIR USE

The assessment process generally will yield a multidimensional set of performance measurements. The specific types of measures are discussed in detail in Chapter 4. **Because some aspects of performance are difficult**

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

or perhaps impossible to quantify, some of these measures may not be numerical. The committee recommends, however, that attempts be made to devise quantitative indicators wherever possible. Such measures help stakeholders and decision makers focus on the relative severity of problems and on the means to address these problems or to realize the vision that motivated assessment.

Arriving at decisions in the face of multiple, conflicting criteria (i.e., resolving what to do when several options have relative advantages over one another) can be a major challenge. **The committee members were familiar with methodologies that have been developed to structure decision making with multiple stakeholders and criteria. The committee found, however, that these methodologies have not been widely used for infrastructure decisions**. Some of the issues related to these methodologies are discussed in Chapter 5. Experience has shown that it is important that the technique not come to dominate the process.

A principal value of the committee's assessment process, described here, is that it structures and promotes interactions among stakeholders leading to a better understanding of community objectives and of the role of infrastructure in realizing those objectives. Building such an understanding is the best way to create performance measurement schemes that are responsive to the needs of decision makers. Even when a consensus is not reached, a structured approach yields the benefits of an orderly framework for debate.[3]

On the other hand, there are costs associated with structured processes and there are limits to how far a process Can take a community in realizing its objectives. The assessment process takes time and money, both of which may be constrained by budgets or the need for rapid action. If the process becomes overly formalized and bureaucratic, it will be of little value for responding to crises or short-term problems, and there is the danger that assessment will be delayed—or intentionally drawn out—and decisions and actions never realized.

If it is successfully carried through to completion, the performance assessment process provides a basis for making decisions and taking action regarding infrastructure development or management. The types of infrastructure decisions that are made fall broadly into three categories (see Figure 3-4): planning (including both early concept development and facility design), implementation (including construction and enterprise formation), and evaluation (as both a prelude to problem solving and a review of what has been accomplished after planning and implementation).

Planning

Planning is generally the earliest stage of infrastructure's evolution. Planning may include such elements as design and priority programming.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Decisions to be made may be structural or policy-oriented, involving construction of new facilities, refurbishment of old ones, pricing and operating policies, establishing or altering land use plans, and other actions typically having the potential for broad systemwide impact. As Figure 3-4 shows, the key question typically shaping the decision concerns the relationship of cost and performance that can be achieved. Planning is often the stage when the community's overall vision is explicitly considered and objectives for infrastructure's role are set. These objectives may include meeting federal mandates or regulations.

Identifying various alternative actions that could achieve objectives or realize the vision is a key step in planning. Stakeholders play an important role in identifying both the alternatives to be considered and their likely impacts. For instance, if the building of a new wastewater treatment plant is one possibility, then one group of stakeholders may raise the issue of nuisance from odor, while others may be more concerned about recycling of waste materials. The articulation of such concerns becomes a basis for establishing objectives and consequently selecting performance measures.

After the various stakeholders are heard and the costs and benefits are weighed, a preferred course of action is chosen. Performance may be only one of several aspects of "benefits" upon which the decision is based. Infrastructure actions may have other benefits indirectly related to the services it is expected to provide, such as giving a temporary boost to the local economy. The decision on a preferred course is then typically reflected in an adopted plan, a capital budget, or some other document that guides subsequent action and decision making.

Implementation

Decisions in the implementation stage are concerned with applying resources efficiently and effectively to realize a previously adopted plan. This stage brings a different set of objectives, now typically having to do with meeting budgets and time schedules and minimizing disruptions from construction or policy change. Stakeholders are likely to include operating entities, construction companies, and the residents of areas where actions will be taken but will typically be a smaller group of institutions and individuals than those involved in the planning stage. However, unresolved planning issues may reappear during implementation as the public reacts to specific policies or projects, shifting performance from what was expected on the basis of previous assessments.

Alternatives to be considered at the implementation stage include detailed aspects of projects selected in planning, such as the staging of construction, selection of process technology (e.g., for waste treatment), and specific hours during which peak-period pricing is to apply. Decisions

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Decision-Making Stage	Key Question and Decision Process
Planning	What will it cost to take actions needed to achieve desirable performance, i.e., to meet specific objectives, satisfy stated goals, or conform to specific regulations?
	Develop vision; set goals and objectives ⇨ Develop, adopt performance measures ⇨ Identify alternative appropriate actions and select a preferred course (e.g., use benefit-cost analysis) ⇨ Adopt plan, allocate resources, and implement plan
Implementation	Given fixed resources (e.g., cost budget), how can action best be carried out to achieve desired performance?
	Set productivity objectives ⇨ Develop, adopt, affirm performance measures ⇨ Identify alternative implementation strategies (e.g., design and construct a facility, impose peak-period pricing) and select preferred one ⇨ Execute strategy, assess costs and achievements
Evaluation	Given that resources were used to take certain actions, are the consequences (outcomes) of those actions consistent with stated and subsequent goals, i.e., is performance "adequate," "good," or otherwise?
	Identify, review outcomes of previous actions, plans, policies, regulations ⇨ Develop, adopt, affirm performance measures ⇨ Measure performance and compare results to goals, objectives, vision to determine if change in the infrastructure system is warranted ⇨ Agree on performance goals (needs, demands, new vision) for subsequent planning and action

FIGURE 3-4 Performance assessment within the decision-making process.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

then represent strategies for plan execution and the start of operational management. Despite the more detailed aspect of implementation decisions, performance measures may reflect broad concerns such as the use of ethnic-minority contractors or employment of workers from a nearby economically disadvantaged neighborhood.

Evaluation

The third stage of decision is evaluation, which concerns the performance of existing infrastructure, that is, whether it is fulfilling the expectations of the community and whether improvements might be made. This third stage may in fact be the first opportunity for an area to undertake performance assessment.

If the process has been applied from planning to this stage, then the objectives set forth in planning, with refinements in the implementation stage, would be the basis for selecting performance measures. However, if the first performance assessment is to be made at the evaluation stage, for example, as an audit of an existing operating entity, performance measures must be developed or adopted from elsewhere. As in other stages, stakeholder input is instrumental in identifying objectives and adopting measures. Decision makers may be aided by benchmarks derived from infrastructure systems in other regions or standards from other levels of government.

In contrast to planning and implementation, there are no clearly defined alternative courses of action to be considered in evaluation. Decision making focuses instead on whether performance is acceptable or needs improvement. A decision that improvement is warranted should initiate a new round of planning, implementation and, eventually, future evaluation. A decision that performance is acceptable should be reconsidered at a later time (e.g., in annual or biennial performance reviews).

LEVELS AND PATHWAYS OF PARTICIPATION AND AUTHORITY

Many institutional units interact in the provision of infrastructure services, for example, agencies at several levels of government, private businesses, public interest groups, and private citizens. The impacts of infrastructure and, consequently, the responsibilities for those impacts cross infrastructure modes; for example, wastewater is generated by stormwater runoff from highways and affect the natural and built environment—air, groundwater and surface water, soils, wildlife, neighborhoods, and cultural and historic monuments. Existing institutions and institutional relationships generally do not match well the scope and structure of these prob

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

lems. Agencies are typically mode-specific, making cross-cutting analysis and management difficult. Dealing with the full range of infrastructure impact, both positive and negative, requires a degree of interagency cooperation within and across levels of government that has rarely been achieved.

Each agency involved in infrastructure management typically has its own objectives and concerns. Some of these concerns may be nested within others (such as the need to control air quality at the national level translating into concerns for traffic congestion at local levels) but may be contradictory (e.g., improving the network connectivity of the interstate highway system versus providing public transit services at the local level). In addition, the impact from the construction or utilization of infrastructure may be felt locally, have regional or national consequences, affect other infrastructure subsystems, and be felt across generations.

For all of these reasons, it can be difficult to determine who makes the important decisions that influence infrastructure performance. The federal government may be involved in providing local infrastructure for a variety of reasons. Water and air pollution resulting from the use of infrastructure have a broad impact that may require federal action to control. National concerns such as security, international competitiveness, and productivity may not match well with local interests. Moreover, there may be insufficient technical, institutional, and financial capacity at lower levels of government to effectively manage all infrastructure.

Nevertheless, **the subsystems of infrastructure exhibit many important functional interactions and relationships in budgeting and management** . When budgets are allocated and used to make substantial improvements in transportation in an area, for example, levels of economic and social activity in that area often rise and increase demands for spending on water supply, waste removal, and other infrastructure services. In such a case, tax revenues often rise as well, although not necessarily enough to pay for increased infrastructure. On a more limited scale, financially constrained governments must allocate tax revenues among competing modes, and cannot increase spending on one element of infrastructure without reducing spending elsewhere. **The committee found that effective performance management generally requires a broad systems perspective encompassing these interactions, despite their often poor match of agency responsibilities**. This broader perspective will generally extend beyond the traditional limits of the public works budget.

There are a number of ways in which different institutional entities can interact to influence decisions and infrastructure performance. Government bodies may enact laws and impose regulatory standards or planning and coordination requirements. Private entities may impose such requirements and standards as well, for example, when banks or insurance com

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

panies insist that borrowers meet certain conditions before financing is provided for infrastructure. Negotiation among stakeholders often is the decisive final basis for decision. Such methods are discussed further in Chapter 5.

In all these cases, performance assessment is a useful tool. As an orderly process yielding a debatable, defensible, outcome-based set of measures, performance assessment supports decision making and subsequent action. **The committee recommends that responsible agencies adopt infrastructure performance measurement and assessment as an ongoing process essential to effective decision making. Adequate budgets should be maintained to support the continuing performance assessment process**.

NOTES

1 "Community" here refers to the broad view of this study, effectively encompassing anyone having an interest in the system at any jurisdictional level.

2 Such conditions raise construction costs so substantially that designers tend to avoid such areas if they can.

3 Reaching consensus often requires compromises that may have as much to do with educating people about the issues or shifting their opinions as with any substantive change in the infrastructure system's behavior. Providing compensation for adverse impacts of infrastructure, for example, is a way of assuring that performance is adequate. Such a strategy is sometimes used successfully to overcome the "Not In My Backyard" response.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

4

MEASURES OF INFRASTRUCTURE PERFORMANCE

The selection of specific measures of infrastructure performance is central to the assessment process. The committee recommends that measures be used that span the three broad dimensions of effectiveness, reliability, and cost, but there are many more detailed concerns that fall within these principal dimensions.

The committee's general measurement framework is the large two-part matrix or table illustrated in Figure 4-1. Rows represent the projects, subsystems, or elements that make up the infrastructure systems being assessed, for example, transportation or water supply, specific transit lines, or landfill operations. Columns in the first part of the table represent the system inventory: indicators of the size, geographic extent, annual costs, employment, and other characteristics of the infrastructure system under consideration. Columns in the second part of the table depict measures of the various aspects of performance selected by stakeholders and decision makers and measured in the assessment process. Taken as a whole, the two-part table presents the results of applying the assessment process described in Chapter 3.

This chapter presents many examples of inventory and performance measures. Because performance should be assessed with the involvement of stakeholders—infrastructure's owners, operators, users, and neighbors—the specific set of measures used may differ from place to place and from time to time, as discussed in chapters 2 and 3, although a desire for comparability across regions may necessitate inclusion of common basic measures. **The committee recommends that local agencies with responsi**

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

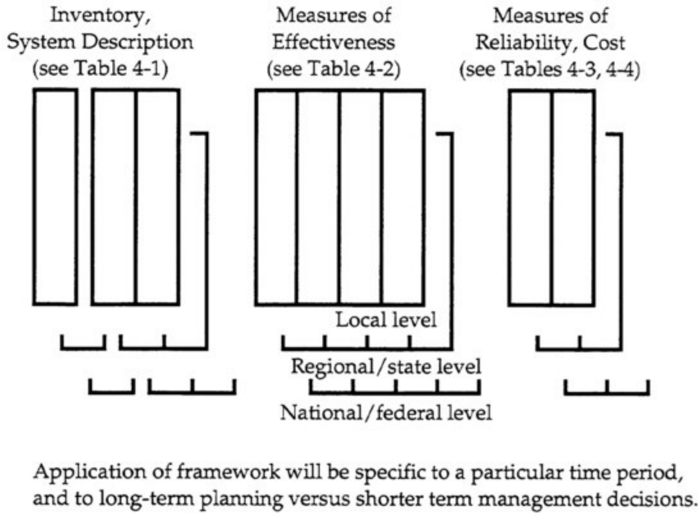


FIGURE 4-1 General framework of performance measures.

bilities for infrastructure management explicitly define a comprehensive set of performance measures. The measures selected should reflect the concerns of stakeholders about the important consequences of infrastructure systems and recognize interrelationships across infrastructure modes and jurisdictions. The committee's framework—in particular, effectiveness, reliability, and cost as the principal dimensions of performance—is a useful basis for defining these measures. There are many sources of example measures on which agencies can draw. At the national level, President Clinton's "Reinventing Government" initiative has generated extensive discussion of how management performance of government agencies can be measured and improved. The Intermodal Surface Transportation Efficiency Act of 1991 has spawned studies in the state departments of transportation to develop measures of intermodal performance.[1] The APWA has issued a report that offers many rules of thumb for assessing local agency management practices. [2] The committee reviewed examples of such work and found them useful but generally less comprehensive and detailed than the framework the committee had in mind.

There are fewer sources of information on the functional interactions across infrastructure modes. Urban planners, for example, have sought to devise mathematical models that can forecast the influence of infrastructure investment on patterns of land use in a metropolitan area. Economists similarly have attempted to assess the influence of total infrastructure

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

investment rates on national and regional economic output. Such efforts have had only limited success and their value remains controversial. The committee concluded that describing these intermodal interactions in ways that can aid decision makers warrants further research.

TAKING STOCK

The first steps in the performance assessment process are directed at developing a broad inventory of the infrastructure system. Table 4-1 illustrates the specific types of measures such an inventory might include.

The first part of the inventory (i.e., the first column in Table 4-1), entails the objectives, goals, aims, or vision that stakeholders set for the system. As indicated by the first row of the table and as discussed in Chapter 2, many measures will be common to all elements of infrastructure, such as those related to economic productivity and opportunity, protection and improvement of public health and safety, protection and enhancement of environmental quality (both natural and built environment), provision of jobs and economic stimulus, and reduction of income inequalities.

Broad goals may be stated more specifically when individual infrastructure modes are considered. Transportation systems, for example, are expected to provide access, mobility, and efficiency of movement. These objectives presumably contribute to economic productivity. Protecting environmental quality (e.g., by reducing air pollution) is a goal that communities may set for the transportation system, beyond the essential service the system delivers. In contrast, municipal waste systems may enhance productivity, but they are intended essentially to protect public health and enhance environmental quality.

The specific size, condition, historical expenditures, technology, and area of extent of the system are then recorded (i.e., as indicated in the next column of the table). If a comprehensive database and monitoring system have been set up in a region, all this information will be readily available. Geographic information systems that many local and regional planning and management agencies are establishing enable the user to display infrastructure system information at varying levels of detail and geographic scope, with relatively lithe effort. Before such information systems were developed, the inventory tasks might have involved laborious data collection, mapping of data, resizing of maps to common scales, and voluminous tabulations. Comprehensive performance assessment under such conditions would be cost-prohibitive for all but the most important decisions.

Inventorying the scope and context of the infrastructure system (i.e., the third column of Table 4-1) involves political, institutional, and social concerns. These data also may be contained in a GIS drawing for example on the U.S. decennial population census, zoning and subdivision records,

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 4-1 Framework and Measures of System Inventory*

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
Generic: all elements or types		
• Enhance economic productivity, opportunity • Improve public health, safety • Protect, enhance environmental quality • Provide jobs and economic stimulus • Reduce income inequalities	• System size • Condition • System cost • Technology • Area of extent	• Political jurisdictions • Formal institutions • Informal, community structure
Examples for Major Classes		
Transportation Systems		
• Improve access • Increase mobility • Move goods efficiently • Protect safety • Reduce air pollution • Increase construction spending • Subsidize public transit operations	• System size – Lane-miles, track-miles – Number of bridges, airports – Fleet size and mix – Area covered, network configuration – Runway length, terminal gates • Condition – Pavement cracking – Bridge load capacity – Track condition • System cost – Replacement cost (construction) – Annual O&M expenditures • Technology – Fuel types – Fleet age distribution • Area of extent – Natural barriers – Airsheds, basins	• Political jurisdictions – System ownership – Pricing authority – Funding and taxing arrangements • Formal institutions – Construction – Operations – Intermodal coordination • Informal, community structure – Ridership – Advocacy groups (e.g., bicycle, pedestrian) – Land developers – Business groups – Environmental resistance groups (e.g., airport noise) – Neighborhood associations
Water Supply		
• Provide adequate, reliable, sources of water • Protect and improve public health • Provide fire protection • Enable and support landscaping, gardening, agriculture • Provide recreation and environmental amenity • Support biodiversity	• System size – Miles of main, distributer – Number of reservoirs, treatment plants – Area piped – Total storage capacity • Condition – Pipe leakage – Reservoir percent of design capacity – Design supply (treatment) capacity • System cost – Replacement cost (construction) – Annual O&M expenditures	• Political jurisdictions – System ownership – Rate-setting, financing – Consumers, service area – Supply sources • Formal institutions – Utility – Regulatory authorities – Bonding, financing authorities • Informal, community structure – Land developers – Major users (e.g., industries) – Recreation interests

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 4-1 Continued

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
	• Technology – Treatment process – Supply main materials • Area of extent – Drainage basins – Catchment areas – Recharge areas	
Wastewater (Sewage and stormwater) • Remove sanitary, industrial wastes • Control, reduce health hazard • Provide flood control, protection	• System size – Miles of main, collector – Number of treatment plants – Area sewered – Separate / combined system • Condition – Pipe leakage, infiltration – Plant percent of design capacity • System cost – Replacement cost (construction) – Annual O&M expenditures – Average unit treatment cost • Technology – Treatment process – Main materials • Area extent – Drainage basins – Recharge areas – Ecosystems, biomes	• Political jurisdictions – System ownership – Service area – Rate setting, financing – Receiving waters – Disposal sites • Formal institutions – Construction – Operations – Maintenance – Regulatory authorities • Informal, community structure – Major producers (e.g., industrial concerns) – Advocacy groups – Treatment and disposal neighbors – Recreational interests
Municipal Waste • Remove wastes • Reduce materials consumption • Avoid exposure of low-income people to toxic materials	• System size – Number of collection vehicles – Number of collection, transfer, disposal sites, facilities – Landfill design capacity – Labor force • Condition – Incinerator age – Landfill percent of design capacity – Haul distance • System cost – Replacement cost (construction) – Annual O&M expenditures	• Political jurisdictions – Collection areas – Disposal sites – Transportation routes • Formal institutions – Municipal agencies – Concessionaires, contractors – Recycling and disposal firms – Regulatory agencies • Informal, community structure – Major producers (e.g., industrial concerns) – Advocacy groups – Treatment and disposal neighbors

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Public Works Element, Type; Example Goals, Objectives	*Scale, Condition, and Geographic Distribution*	*Scope and Context*
	• Technology - Disposal system and processes - Recycling processes • Area extent - Ecosystems, biomes - Airsheds - Groundwater regimes	

* Assessment may be made at local, regional, or national level; level will influence choice of appropriate inventory descriptors. Specific goals and objectives may vary substantially among particular projects and programs. Absence of a goal objective, or descriptor does not necessarily imply that the missing item is not relevant to the type of infrastructure being considered. The four major classes shown are based on the work of the NCPWI; other infrastructure modes could be included. The table serves as an example and should be revised to suit specific applications of the framework

public health and education department records, and the like. In some cases, useful data have been collected by city or state agencies, but differing formats and frequency of data collection from different sources may not allow easy comparison of projects or systems across jurisdictions. Sometimes a major infrastructure project provides an opportunity for assembling a database that can subsequently be maintained for other uses.

Taken as a whole, the inventory represented by measures in Table 4-1 is a snapshot of the infrastructure system as seen from several perspectives. Like a photograph, the inventory represents a particular time and is taken to serve a particular function, giving perhaps a closeup look at some small part of a region's infrastructure or a broad view of the region within a statewide context. For example, if the performance of a single sewage treatment plant is being measured, the inventory will be a "closeup" listing of particular equipment such as filters, aerators, and chlorinators, but if the decision to be made concerns federal policies to reduce untreated overflow from combined sewer systems nationwide, such detail in the inventory of combined systems would be superfluous.

Data availability can influence the clarity and coverage of this inventory snapshot. Some data are collected to meet the requirements of particular aspects of public policy and are restricted in their coverage. For example, health data reported to the Centers for Disease Control in Atlanta, are aggregated and archived at the National Center for Health Statistics. Such data can often be used to establish regional baselines or look for trends

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

that indicate changes in infrastructure performance. Similarly, the National Highway Transportation Safety Administration (NHTSA) maintains files of accident statistics, and the Environmental Protection Agency maintains water pollution data under the auspices of the National Pollution Discharge Elimination System (NPDES). Data files on hazardous materials transport and the sites of known toxic wastes have also been assembled. Because these data sources lack common purpose, assembly of the data and their analysis for infrastructure performance assessment can be inordinately challenging and expensive.

DATA AS A CONCERN

Sometimes data are not immediately available because data collection is felt by government officials to be too costly or insufficiently useful, or because private-sector firms offer it at prices that public agencies have been unwilling to pay. Demonstrating the usefulness of data will prompt data collection and justify its cost. This demonstration can occur by showing how other jurisdictions are using data or, over time, by innovation that presents new data requirements. For instance, 20 years ago few firms kept track of the true costs of inventory because of the way most firms were functionally organized. When the field of logistics developed, it was demonstrated that goods in inventory have an opportunity cost (turned into cash, the goods could be invested and return interest). Once this was recognized, carrying cost of inventory became and continues to be standard practice for firms. The costs existed 20 years ago, but they were not recognized. The lesson is that those who do not collect data today may need to be educated as to the potential use of such data.

A tradeoff must generally be made between desirability and availability of data. Over time a prototype system and formats for data collection may be developed that will greatly reduce the effort required in this inventory stage of performance assessment. Such a system might be analogous to the Generally Acceptable Accounting Procedures used in monitoring private businesses' financial performance. Knowledge of political and economic relationships within the region may be less formally inventoried but is embodied in the participation of key stakeholders and so becomes an informal part of the inventory.

The committee found that lack of data and subsequent inability to measure the infrastructure system and its performance in many cases limits the system's susceptibility to effective management. The committee therefore recommends that data be collected on a continuing basis to enable long-term performance measurement and assessment. Each region with infrastructure decision making authority should establish a system for continuing data collection to maintain its infrastructure

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

inventory and enable longer-term performance monitoring. Metropolitan areas with basic databases and modeling tools already in place should seek to integrate information on separate infrastructure modes into a uniform and accessible system so that existing data sets are documented in consistent ways and within the context of relevant national data collection activities such as the NPDES, NHTSA, and Centers for Disease Control programs already mentioned. These federal agencies should ensure that their national data sets are compatible with one another (e.g., in geographic detail, time periods, and indexing), computerized, and available on line to users via computer and telecommunications access modes. The committee recognized that many metropolitan areas do not have an agency with clearly defined responsibility or authority to assemble such data. State and federal agencies have the scope to serve as catalysts for establishing regional data collection programs, as the preceding discussion illustrates, but the effort should have a firm local base if it is to succeed. Often an individual local government official or a nongovernmental entity (e.g., a university-based research center) willing to assume leadership can be instrumental in this effort.

PRINCIPLES FOR SELECTING PERFORMANCE MEASURES

Once the inventory has been made, performance measures must be selected or developed. Tables 4-2, 4-3, and 4-4 display a range of example measures for, effectiveness, reliability, and cost, respectively. As the committee frequently reminded itself throughout its deliberations, the point of assessing infrastructure performance is to provide a better basis for decision making about how resources are used and, ultimately, to enhance the performance of infrastructure in particular regions. Starting from this premise, the committee agreed on several principles that should guide the selection of performance measures:

1. Each measure of performance should be meaningful and appropriate to the needs of the decision makers (e.g., elected and other officials, business community, citizens groups, local residents), such that

each measure reflects specific goals, regulations, or community vision of the purposes of its infrastructure;

the measures indicate the outcomes resulting from infrastructure service availability and delivery (e.g., access and movement, health, economic activity, safety);

the measures reflect local conditions and current or pending issues and decisions to be made;

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

the measures facilitate comparisons among alternative means of providing the service, for example, private versus public sector, regional versus local management, alternative agencies or departments responsible; and

all stakeholders can accept each measure as a meaningful and objectively measurable indicator or as a reasonable proxy upon which discussion may be based.

2. As a set, measures should support a thorough assessment of performance in which

all important management concerns are addressed;

there is a balanced treatment of qualitative as well as quantitative aspects of performance;

trends indicating likely future performance during the facility life cycle can be observed;

preventive as well as corrective management actions can be considered to maintain acceptable performance throughout the facility life cycle;

asset values and depreciation of facilities and equipment during the facility life cycle can be assessed; and

comparisons of performance across regions are facilitated when multiregional funding or management issues are involved.

3. The costs of measurement should be reasonable in relation to

the costs of actions being considered;

the possible consequences of the decisions and the value stakeholders place on those consequences; and

the possibility that changes in goals or regulations will alter the set of appropriate measures and needs for data.

The decision-making environment; the nature of the decision-making process; who derides what is to be done at the local, state, and federal levels; and why certain decisions are made define the context within which performance measures will be used to achieve improvement. These principles must be applied within that context—that is, by stakeholders undertaking the assessment process described in Chapter 3.

MEASURES OF EFFECTIVENESS

The committee proposed that effectiveness—the ability of the system to provide the services the community expects—may generally be described in terms of its capacity and delivery of services, the quality of services delivered, the system's compliance with regulatory concerns, and the system's broad impact on the community. As Table 4-2 illustrates, each of these four aspects of effectiveness encompasses an extensive and varied

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 4-2 Framework and Measures of System Effectiveness*

Inventory (Table 4-1)	*Dimensions, Indicators, and Example Measures of Effectiveness**			
Public works element, type	Service Delivery/Capacity (engineering specifications, technical output, quantity delivered; supply and consumption)	Quality of Service to Users (customer acceptance, satisfaction, willingness to pay)	Regulatory Concerns	Community Concerns, Community-wide Impact, Externalities
Generic: all elements or types	• Output (per unit time, e.g., hour, day, month; peak, average, minimum) • Technical productivity (output per unit input) • Utilization (per unit time, e.g., hour, day, month; peak, average, minimum) • Access/coverage (e.g., fraction of population served) • Contingency	• Consumer Safety • Satisfaction • Availability on demand/ congestion • Environmental/ ecological quality	• Service-related (i.e., pricing) • External (i.e., Clean Air Act)	• Economic impact • Public health & safety • Social well-being (quality of life) • Environmental residuals and byproducts (i.e., pollution & other NEPA impacts) • National security • Equity (i.e., distribution of costs, benefits, consequences)

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness*[*]			
Transportation Systems	• Output - Vehicle movements - Seat-miles - Route closures (hours), breakdowns • Technical productivity - Seat-miles per labor hour - Seat-miles per route mile - Operating cost per passenger - Passenger-miles per seat mile - Percent of bridges with weight restriction noise emission targets - Average fuel consumption - Average fuel consumption • Utilization - Mode split - Trip purpose distribution - Number of trips - Passenger-miles • Access/coverage - By jurisdiction - Special segments (e.g., mobility impaired) • Contingency - Emergency response capability - Severe weather response experience	• Consumer Safety - Accident events - Value of losses - Fatalities per capita total, or per annual user • Satisfaction - Level of service - Average speed - Space per passenger - On-time service - Fare, cost to use - Ride quality • Availability on demand - Average wait time - Route closures (hours), breakdowns • Environmental/ ecological quality - Air pollution emissions rates - Road treatment chemical pollution (e.g., winter salt)	• Service-related - Access to international routes - Vehicle inspection effectiveness - Speed limits • External - Noise control restrictions - Air pollution emissions restrictions • Fleet fuel efficiency standards	• Economic impact - Person-hours of travel time • Transport industry sales - Access-based property value increases • Public health & safety - Pedestrian accident rate • Social well-being - Neighborhood disruption - Construction/repair disruptions • Residuals and other NEPA impacts - Construction wastes - Road salt in stormwater runoff • National security a. Bridge heights adequate for military vehicles • Equity - Income versus mode split communities - Service to minority communities

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness*[*]			
Water Supply	• Output - Gallons treated - Storage volume - Maximum head (pressure) • Technical productivity - Cost per gallon - Leakage/loss rate - Removable trace contaminants • Utilization - Per capita consumption • Access/coverage - Supply area - Recycling volumes • Contingency - Fire delivery pressure - Reserve storage	• Consumer safety - Main breaks - Fire protection service coverage - Disease outbreak incidents • Satisfaction - Water taste, color • Availability on demand - Reservoir capacity versus demand (days) - Service outages, restrictions • Environmental/ ecological quality - Low flow restrictions	• Service-related - Conformance to Safe Drinking Water Act standards • External - Heavy metals in sludge - Water drawn from wetlands sources	• Economic impact - Water use restrictions • Public health & safety - Worker accident rates • Social well-being - Houses with indoor plumbing - Public drinking fountains • Residuals & other NEPA impacts - Treatment chemical waste • Construction/repair disruptions • National security - Protection from terrorist acts • Equity - Catchment area versus service area b. Low income houses with indoor plumbing

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness**			
Wastewater (Sewage and stormwater)	• Output - Gallons treated - Stormwater storage volume • Technical productivity - Cost per gallon - COD/BOD reduction - Sludge load - Percent of heavy metals, other toxics removed - Sewered area per mile of main • Utilization - Per capita sewage treated • Access/coverage - Sewered area • Contingency - Capability to respond to toxics overload - Overflow frequency (combined systems)	• Consumer Safety - Main breaks - Infiltration to water supply - Compliance with NPDES requirements • Satisfaction - Back-up, retention, overflow during peak load periods - Noxious odor • Availability on demand - Peak capacity limitations - Overflow incidence • Environmental/ ecological quality - Wetlands habitats threatened by runoff - Receiving waters quality	• Service-related - Effluent restrictions • External - Endangered Species Act restrictions	• Economic impact - Wastewater treatment requirements (e.g., for factories) • Public health & safety - Disease outbreak incidents - Worker accident rates • Social well-being - Homes on system • Residuals & other NEPA impacts - Construction/repair disruptions - Landfill volumes - Hazardous by-products - Odor in plant area • National security • Equity - Distribution of flooding by neighborhoods - Disposal impact area versus service area

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Major Classes	*Typical Example Measures of Effectiveness**			
Municipal Waste	• Output - Tons collectable - Special waste collection, disposal potential (e.g., medical, nuclear) • Technical productivity - Cost per ton - Tons collected per truck - Ton-miles haul per ton • Utilization - Tons collected, per capita or per job • Access/coverage - Collection area - Industrial customers • Contingency - Alternatives in event of pollution regulatory change	• Consumer safety - Hazardous waste control • Satisfaction - Community perception of risk - Storage space required per household, employee • Availability on demand - Disposal reserve capacity to accommodate growth - Disposal restrictions • Environmental/ ecological quality - Air, water pollution emissions	• Service-related - Recycling requirements - Incinerator moritoria • External - Clean Air Act restrictions	• Economic impact - Disposal restrictions - Resource recovery - Landfill areas with restricted development potential • Public health & safety - Worker accident rates • Social well-being - Street cleanliness • Residuals & other NEPA impacts - Incinerator emissions - Wetlands affected - Population exposed to disposal site effects • National security • Equity - People adjacent to disposal sites, haul routes

* Dimensions and measures may be added or deleted to match local objectives. Absence of measures does not necessarily imply that indicator is less relevant to the type of infrastructure being considered. All measures may be determined at particular reliability levels. The table serves as an example and should be modified to suit specific projects and programs.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 4-3 Examples of Measures of System Reliability

Type of indicator, measure	*Example measures*
Deterministic	a. Engineering safety factors b. Percentage contingency allowances c. Risk class ratings
Statistical, probabilistic	d. Confidence limits e. Conditional probabilities (Bayesian statistics) f. Risk functions
Composite (typically deterministic indicators of statistical variation)	g. Demand peak indicators h. Peak-to-capacity ratios i. Return frequency (e.g., floods) j. Fault-tree analysis

TABLE 4-4 Examples of Measures of System Cost

Basic indicator	*Example measures*
1. Investment, replacement, capital, or initial cost	a. Planning and design costs b. Construction costs c. Equity d. Debt
2. Recurrent or O&M cost	a. Operations costs b. Maintenance costs c. Repair and replacement costs d. Depreciation costs e. Depletion costs
3. Timing and source	a. Timing of expenditure b. Discount and interest rates c. Exchange rates and restrictions (e.g., local versus foreign currency) d. Sources of funds, by program (e.g., federal or state, taxing authority) e. Service life

set of specific indicators and measures. As discussed with respect to the inventory and Table 4-1), many types of measures are generic to all modes of infrastructure. These generic measures, shown in the first row of Table 4-2, derive directly from the goals and objectives of infrastructure. Each one, however, may require a list of several more detailed subsidiary measures to reflect the concerns of a particular mode's performance. Many of these more detailed measures are suggested in the mode-specific rows of Table 4-2.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

"Service delivery/capacity" and "quality of service to users," in the second and third columns of Table 4-2, include many of the concerns that engineers, planners, public health personnel, and other infrastructure professionals seek to address in design and system management. Items in the fourth column (regulatory concerns) also are addressed by these professionals but often are treated as a check on feasibility after the system's principal configuration has been determined. For example, highway engineers consider whether ambient air quality standards in a region are likely to be violated but seldom adjust highway pavement and intersection designs to reduce pollution emissions.[3]

A primary usefulness of measures in assessment is in the design guidelines, codes, regulatory standards, and other indicators that infrastructure professionals routinely use in their work. The decision makers undertaking a performance assessment should carefully examine each indicator to ensure that the measure really reflects stakeholders' current interests rather than some abstract or obsolete concept of "need" (as discussed in Chapter 2).

The final column in Table 4-2, "other community concerns or impacts," includes many items that fall outside of the scope of the immediate requirements placed on the system. While economists refer to many of these items as "externalities," they often have immediate importance in decision making. For example, Portland's light raft transit system maintains its strong political support in part because its service encourages concentration of economic development along the train's route. This concentration yields benefits in terms of control of land as well as enhanced public demand for transit. Many communities are coming to recognize the importance of infrastructure's impact on the social, cultural, and aesthetic aspects of our environment. This fourth dimension of performance encompasses such matters as whether a highway in Baltimore divides or obliterates a formerly vibrant neighborhood, whether a ventilation tower in Boston is obtrusive within the architectural context of its surroundings, and how effectively the water-supply canals in Phoenix convey the significance of water and the importance of conserving it in the desert setting.

Over time there is a tendency for public values to shift, bringing so-called externalities into the mainstream of decision making. For example, clean air was taken for granted in the planning and management of cities until motor-vehicle pollution emissions were found to be an important contributor to declining air quality in urban regions. Rising public concerns eventually led to passage of federal legislation that imposed emissions restrictions on vehicles and set ambient air quality standards. This tendency of values to change means that new aspects of performance may arise and be listed in this fourth dimension, as others already listed move toward the columns to the left.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

The measures included in Table 4-2 are meant to be a comprehensive but by no means exhaustive listing of performance indicators. As was the case for inventory measures, many effectiveness measures apply broadly to all modes. These generic measures (e.g., system output, user safety, economic effect) are shown in the first row of the table. More detailed measures, illustrated in subsequent rows, may apply to only a single mode or project. The particular measures used in any specific situation will depend on the scope and type of the decision to be made and the stakeholders in that decision. For example, decision makers concerned primarily about protection of public health will rely on indicators such as mortality, morbidity, and disability rates, rates of occurrence of specific sentinel illnesses, and costs of hospitalization and liability compensation. Federal agencies concerned with national spending and standards will want comparative local and regional analyses made using common measures specific to their programs. As explained in Chapter 3, the exercise of identifying and seeking to resolve conflicts among objectives and performance measures is an important part of the assessment process. Such comparative analyses, when linked to information on infrastructure design and management, can yield valuable insights on the merits of particular design and management practices.

MEASURES OF RELIABILITY

Performance measurement must unavoidably deal with uncertainty. This uncertainty stems first from the inherently statistical character of natural phenomena (e.g., the daily flow of water in a stream) with which infrastructure must contend and the characteristics (e.g., material strength, pipe condition, worker health) of the infrastructure itself. Added uncertainty comes from the inadequacies of data, many of which have been discussed in this report. Finally, assessing performance when changes in the system are being made requires forecasting of future conditions, which introduces more uncertainties. Reliability is a measure of these uncertainties.

Reliability is described as the likelihood that infrastructure effectiveness will be maintained over an extended period of time or the probability that service will be available at least at specified levels and times during the design life of the infrastructure system. In principle each measure of effectiveness can be expressed in statistical terms. The confidence level at which the measurement is made is then an indicator of reliability with respect to that particular measure of effectiveness.[4]

Reliability is influenced by planning and implementation decisions as well as inherent uncertainties in the infrastructure system. Construction and operations often extend over periods of many years and affect characteristics of infrastructure elements and their behavior. People make judg

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

ments about the value or severity of outcomes of infrastructure-related decisions, also influencing reliability.

For example, suppose heavier-than-average rainfall in an area caused slope failures that damaged pipelines, blocked highways, and seriously degraded water and energy supplies and road access for a large number of people. Initial measurements of soils properties, an important basis for designing the facilities, depended on a limited number of samples and tests. If development in the area were anticipated to be low, then decisions may have been made to accept a somewhat higher risk of slope failure. In hindsight, one might question whether adequate soil samples were taken or whether design assumptions were made wisely but, at the time, the responsible decision makers may have dealt with the uncertainties as well as they could.

Collecting statistical data for large numbers of measures is costly and time-consuming. In addition, some indicators may not be quantified or easily measured in numerical terms. Other indicators of reliability may then be useful. Table 4-3 lists some of these measures.

Reliability measures generally apply to all infrastructure modes but may be expressed differently from one application to the next. For example, many aspects of water supply and wastewater infrastructure are analyzed in terms of an anticipated peak flood or water flow. The peak is stated in terms of its anticipated frequency of recurrence, (e.g., the "100-year flood"). Similarly, many aspects of transportation infrastructure are analyzed in terms of a relatively infrequent peak level of traffic, for example, the "peak hour of the average day in the peak month" or the "100th busiest hour." Such measures may be used as indicators of reliability.

Engineers and other infrastructure professionals sometimes use a contingency allowance or "safety factor" to assess such parameters as structural load-carrying capacity.[5] A higher safety factor is an indicator of greater reliability.

As in the case of effectiveness, the specific measures may be selected to suit the problem or needs of the community and the decisions to be made. Regardless of which measures are selected, however, explicit recognition of uncertainty is a key element of the committee's concept of infrastructure performance.

MEASURES OF COST

Measuring infrastructure costs is often a complex financial exercise that goes well beyond simply recording expenditures for facilities construction, operations, and maintenance. The basic elements of expenditure, from which indicators of cost are derived, are included among the inventory measures in Table 4-1. As shown there, consideration must generally be

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

given to the initial construction or replacement cost of facilities (also called investment or capital cost) and the recurring expenditures for operations and maintenance that will be required throughout the system's service life.

Measures of cost will generally reflect such factors as the source of funds (i.e., who pays), timing of expenditures, and relative preferences for short-or long-term commitments. Table 4-4 presents a framework of factors that will influence cost measures. While costs are almost always measured in dollars or some other currency, the actual measure may be an equivalent present value of past and future expenditures, an equivalent uniform annual expenditure, an implied effective rate of return on investment, or some other computed indicator. The calculations may encompass all expenditures or other resource requirements, or only those coming from particular sources.

For example, federal government programs that provide funds for state or local construction of new facilities may encourage much more construction than would otherwise be undertaken within the limits of state and local funding. The state or local government may then be responsible for operation and maintenance expenses for new facilities but have no adequate source of revenue to pay these costs. In contrast, private bond lenders may require that an infrastructure agency (e.g., a toll authority) seeking to borrow money for new construction collect and specifically reserve adequate revenues to cover these future expenses as well as to repay the borrowed amount. Whether a government agency or other entity has the ability and authority to tax or charge fees to recover the costs of infrastructure will also influence how some costs are viewed. Both budgetary and functional aspects of performance typically will influence decision making.

BENCHMARKS AND STANDARDS FOR ASSESSMENT

Understanding the measures of effectiveness, reliability, and cost in a particular situation is generally accomplished by comparing the measurements to some example or base. The base may be informal and derived from experience, as is the case when most people recognize that traffic congestion on a particular highway is severe or that brown water flowing from the tap is abnormal. Rules of thumb may provide somewhat more formal and numerical bases for judgment; for example, more than 10 people standing in line to check in at the airline ticket counter will represent a significant delay for travelers.

In principle, a complete set of such bases is required for performance to be assessed. These bases for judgment are generally termed "benchmarks" and "standards."

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

A benchmark is typically developed by observing the past behavior of a system or of comparable systems. For example, an airport may compare its total annual number of originating passengers to the benchmark of the previous year's count. An airline may compare its monthly average load factor to the reported industrywide average. [6] Availability of regularly collected data enables benchmarking and thereby facilities comparisons over time or among regions.

When the basis for comparison is formally adopted by law, regulation, industry convention, or a consensus among stakeholders, it becomes a standard. Air pollution levels that exceed federal standards are a violation of enforceable regulations. Passenger delays exceeding 10 minutes for checking in at the airport ticket counter may be unsatisfactory in terms of the service standard an airline sets for itself. Standards may be derived from benchmarks, theoretical analyses, cross-sectional analyses, or other sources.

The committee recommends that benchmarks or standards be developed for all measures of infrastructure performance. Data collection activities should be designed to facilitate benchmarking (e.g., by ensuring that comparable data are collected in different regions), and emphasis should be given to those aspects of performance for which data on past performance are especially sparse, such as stormwater runoff from transportation facilities and reliability of waste recycling processes.

USING PERFORMANCE MEASURES

The final result of assessment, the "bottom line," is a judgment that performance is adequate or good, or that it needs improvement. In this assessment, effectiveness, reliability, and cost interact with one another in complex ways, both functionally and in terms of how stakeholders and decision makers will make their judgments. High construction or maintenance costs, constraints on program funding available to cover certain types of cost, high interest costs, or potentially adverse consequences for some stakeholders, to suggest a few examples, lead decision makers to change their objectives or modify their priorities. The overall performance assessment will involve weighing and effectively trading off the various aspects of effectiveness, reliability, and cost.

In its visits to Baltimore, Portland, and the Twin Cities, the committee heard about situations in which performance assessment was used effectively or could have helped support public discussion. The committee selected one such case as a basis for illustrating how a complete performance assessment might be made. Table 4-5 summarizes this hypothetical performance assessment, prepared by the committee using a situation described in Minneapolis. The final assessment findings reflect the com

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

mittee's views but are meant to be consistent with the conclusions drawn by community leaders, acting as stakeholders themselves, and representatives of commuters and other stakeholders who did not actually participate in the assessment.

The situation concerns evaluation of an existing highway planned initially to have six lanes but constructed with only four. Two lanes were eliminated because of public concerns expressed about increased air pollution, neighborhood disruption, and other local impacts anticipated to occur when the new road was developed. However, no restriction was placed on land development, which grew substantially along the route once the new highway was opened to traffic. New development increased traffic on the highway, and the resulting traffic congestion brought with it not only the pollution originally feared but also lost time for commuters and concerns that downtown economic activities risked being strangled. Construction of a rail transit system has been proposed by some community members as a solution to the problem.

Transportation studies made by local agencies indicate that such a transit system is unlikely to enhance overall system effectiveness, measured in such terms as average travel times, downtown travel, or energy consumption, because dispersed development patterns and the high cost of transit service seem likely to keep ridership low. The cost of developing and operating the transit system would be substantial, imposing high fiscal burdens on local and state governments. Overall performance of the Twin Cities' infrastructure seems unlikely to improve significantly with construction of raft transit, as proposed. [7]

However, community leaders agree that the threat to the downtown economy seems to warrant other action. New technologies (e.g., intelligent highway-vehicle systems) may offer substantially improved traffic flow over the problem route and other parts of the regional network, reducing air pollution as well as relieving congestion.[8] In the shorter term, traffic congestion might be relieved by diverting from the problem highway those vehicles bound for destinations outside the downtown area. These conclusions represent the completion of a performance assessment for making a planning decision. Subsequent repetitions of the process could involve location studies and designs for highway construction. The state and local transportation agencies' public participation and environmental review requirements would substantially broaden the base of stakeholders involved in these future rounds of assessment. The committee's example is necessarily brief and highly schematic. An actual performance assessment would include a significant depth of analysis and documentation. The level of analysis—and its cost—would depend on the nature of the decision to be made and the likely scrutiny to which the decision would be submitted. For example, a controversial situation subject to federal and

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

TABLE 4-5 Example of Performance Measurement*

Stage or product of assessment	*Information, measures, and findings*
Inventory	
System and motivation for assessment	In town urban interstate highway was planned for six lanes as part of regional system but constructed with four lanes because of community. concerns for noise, air pollution, and neighborhood disruption. Subsequent urban growth in the corridor has generated high travel demand and daily long hours of congestion, contributing in turn to recurring episodes of ambient air pollution levels above federal standards
Goals, vision	• Enhance mobility in region • Serve and facilitate continued economic growth in corridor • Reduce air pollution levels by relieving congestion • Make region a center for information and related electronics industries
Scale, condition, geographic distribution	• Approximately 10 miles of four-lane urban expressway, in good condition • Entry ramps to left lane are common
Scope and context	• Federal funds are available for highway construction and rehabilitation • Federal funds may be available for capital expenditures for transit system expansion or upgrading • Segment serves primarily suburban commuters travelling to and through downtown area • State has established regional transit authority that operates public transit system; state transportation department retains authority for highway construction and improvements
Effectiveness measures	
Capacity/delivery of services	• Average daily traffic on the road is approximately four times planned capacity • Average daily rate of trips per capita in region is double what it was when the road was planned • Transit ridership has declined in absolute terms
Quality of services	• Each direction of segment operates at level-of-service "D" or below for approximately four hours each weekday • Frequent accidents at entry ramps • Air pollution emissions are high
Regulatory concerns	• EPA requires transportation control strategy to reduce ambient levels of pollutants

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Stage or product of assessment	*Information, measures, and findings*
Community concerns	• Commuters losing hours of time, productivity • Access to downtown businesses substantially reduced • Downtown economic vitality is threatened
Reliability measures	• System has failed, relative to standards set when road was planned and constructed • Likelihood of future service improvements is low, unless action is taken
Cost measures	• Road constructed with 90 percent federal funding • Maintenance costs under current situation are not a problem for state
Assessment of performance	Threat to downtown vitality, warrants action to relieve congestion, but substantial shift to transit seems unlikely. New construction/upgrading of roads to divert traffic not destined for downtown should be explored. Over longer term, develop "intelligent vehicle-highway systems" to improve flow on route.

* This example is based on the committee's observations in Minneapolis, Minnesota, but reflect the committee's views and findings only. Rows in this table correspond to columns in tables 4-1, 4-2, 4-3, and 4-4.

state environmental reviews might warrant a great deal more analysis than a strategic planning discussion undertaken by community leaders following the start of a new political administration.

Regardless of the level of depth and detail, infrastructure systems are so complex that one can only infer that an observed change in a performance measure—for example, the congestion that motivated this example assessment—is a consequence of actions initiated by the system's planner or manager. External events may have caused or partially caused the change. However, the inferred linkage of changes in performance to actions taken to implement decisions, for example, construction of the highway with only two lanes in each direction and no means to limit or direct urban growth, is a crucial step in assessment, marking the transition from one decision cycle to the next.

In making this transition, decision makers are seeking to improve performance. Generally speaking, performance is clearly improved if one of the following two conditions is met:

1. Some measures of effectiveness or reliability (or both) improve and none deteriorate, while costs decrease or do not change.
2. Some measures of costs decrease and none increase, while no measures of effectiveness or reliability change.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Such conditions characterize a proposal that clearly is what decision analysts term "nondominated" (as discussed in Chapter 5), and the decision that improvement has occurred is straightforward. Even if one of these conditions is not met, however, performance may be judged to have improved if the community gives sufficiently greater weight to the measures that have improved compared with those that have not. For example, residents of some neighborhoods request installation of speed bumps on their local streets even if their. taxes are raised to recover the public works expenditure. These residents prefer to sacrifice their riding quality to achieve the improved safety they attribute to reduced speed of other vehicles passing through the neighborhood.

NOTES

1 Agencies and researchers in Oregon, Pennsylvania, Louisiana, and Minnesota, to name only a few, have presented their work in national forums. Finland and the members of the European Union are also pursuing such work.

2 public Works Management Practices, APWA Special Report #59, American Public Works Association, Chicago, August 1991.

3 They may, however, adjust route alignments or traffic signal timing because the consequent reductions in pollution emitted are more immediate and substantial.

4 "Confidence level" is a term used in statistics. A parameter that is known to have statistical variation (e.g., the strength of concrete) is estimated by testing samples and then computing from these tests a value for the parameter and the confidence one may have, on the basis of the tests, that the actual value of other (untested) samples are equal to or greater than the computed value.

5 "Safety factor" is generally defined as the ratio of the projected load at which failure would occur to the maximum anticipated load. A safety factor greater than 1.0 is considered safe. However, because of uncertainties in measurement and projection, common practice and sometimes building codes and other regulations may require that facilities be built and operated with safety factors of 1.5, 2.0, or higher.

6 "Load factor" is typically defined as the ratio of paid passengers to available seats on an aircraft, as a percentage. An airline might hope to maintain its load factors greater than, say, 65 percent.

7 The committee did note, however, that their visit to Portland illustrated where a different conclusion was drawn by local decision makers committed to implementing land use, parking, and other incentives or restrictions aimed at increasing transit ridership and discouraging automobile usage for downtown travel. Some stakeholders in the Twin Cities area will undoubtedly continue to maintain interest in rail transit development.

8 The committee was told that the University of Minnesota, aided in part by funding from the U.S. Department of Transportation, is active in research in this area.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

5

INFRASTRUCTURE IMPROVEMENT THROUGH PERFORMANCE-BASED MANAGEMENT

As illustrated at the conclusion of Chapter 4, the result of applying the committee's process and framework will be a multidimensional assessment of the performance of a particular infrastructure system. Certainly there are challenges in making this assessment, as has been discussed: the involvement of many stakeholders, dealing with multiple measures of performance, collecting and analyzing required data, and adjusting the assessment process to the specific decision situation.

There are also other issues in infrastructure decision making based on performance assessment. The committee discussed these issues in three principal areas: (1) dealing with multiple objectives, dimensions of performance, and stakeholders' points of view, (2) dealing with multiple jurisdictions and multiple infrastructure modes to reach conclusions about system performance, and (3) the significance of uncertainty and risk in infrastructure decisions.

MULTIPLE OBJECTIVES AND VIEWS

Infrastructure performance has multiple dimensions, essentially because infrastructure is intended to serve multiple objectives. The explicit recognition of the multi-objective nature of performance in the assessment process will help create an environment in which decision makers and analysts are able to maintain appropriate roles and in which information essential to effective decision making can be generated and conveyed. Explicitly dealing with the multiple points of view that inevitably come

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

into play helps to ensure that decisions are consistent with public views and less likely to encounter the resistance embodied in the "Not In My Backyard" response to infrastructure actions.

Considering Multiple Objectives

A fundamental feature of multi-objective problems is that there is no single, optimal solution. Instead, the focus of problem solving and decision making is finding a set of solutions that seem "better" than others, that is, they are not clearly dominated by any other, and exploring the tradeoffs among the objectives implied by choosing one of these "better" (i.e., nondominated, noninferior, efficient, or Pareto optimal) solutions over another. In other words, the measure of good infrastructure decision making is that no one can produce a clearly better plan of action.

Over the last 25 years, dozens of techniques have been developed for analyzing multi-objective problems.[1] Rich in variety, reflecting the range of problems and decision contexts for which they were developed, the methods can be conveniently grouped into two categories: generating methods and preference-oriented methods.

As the name implies, generating methods are particularly useful for generating "better" solutions to a problem. Their aim is to create either an approximation or exact representation of the set of nondominated solutions, which will form the basis for exploration of the tradeoffs among objectives. There is no attempt made to incorporate decision makers' preferences in any formal or explicit manner.

By contrast, preference-oriented use explicit quantitative statements of decision makers' preferences to identify a preferred solution (Cohon, 1978). Though preference-oriented techniques can help policy makers understand the implications of preferences and preference conflicts for decision making, many of them suffer from several disadvantages. They tend to reveal little information about the set of "better" solutions, thus limiting the insight gained from analysis. Also, they are rigid in the way preferences must be stated and are sensitive to characteristics of decision making processes typical of environmental problems. The presence of multiple decision makers can cause complications that defeat most of the preference-based methods.

A combination of methods often works best. A generating technique would be emphasized first to develop an appreciation of the range of choices and the tradeoffs. The planning workshop or design "charette" sometimes used for infrastructure planning is an example of a generating method.[2] In reacting to the results generated, decision makers may be able to articulate preferences, for instance, a particular portion of the nondominated set worthy of further, detailed exploration.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

A key to the successful implementation of a multi-objective analysis lies in early and frequent involvement of all participants. In that very important sense, the theoretical foundations of multi-objective methods can be viewed as defining the assessment process described in this study. The multiple objective methods do not and probably should not yield single solutions to problems, however comforting that prospect might seem. Instead, these methods and the infrastructure performance assessment process highlight tradeoffs that must be made in the real world of decision making.

The specifics of how to convey tradeoffs to decision makers in an accessible manner are themselves challenging from several viewpoints. At the heart of most of these challenges is the rapid increase in dimensionality mentioned earlier. With only two or three objectives, choices and tradeoffs may be illustrated by conventional two-and three-dimensional graphs. It is not at all obvious how best to visually portray a tradeoff response surface in, say, four or five dimensions. The option always exists of showing just two-dimensional slices of the surface at a time (e.g., between highway speed limit and likely accident rates), but such an approach can sometimes fail to convey an appreciation for the interconnectedness of the problem across all dimensions.

Some success has been achieved with projection formats, notably the value path, in which all objective values are projected to parallel (usually normalized) scales and the points on these scales associated with a particular solution connected to show that they indeed do represent one solution alternative.[3] Such approaches can effectively deal with certain of the other problematic aspects of real-world decision-making problems, specifically the presence of noncommensurate objectives. The scales in a value path can represent a common quantified metric (e.g., dollars, noise levels, maximum wait times), but they can also represent qualitative measures, (e.g., most to least preferable aesthetic attributes). Note that for this latter objective the need for quantification is not eliminated; the quantification is kept implicit in the display. This in turn points up another important caveat. The intent here is most assuredly not to deceive the user that qualitative objectives somehow escape the need for quantification. Assumptions must be clearly stated and the details of the underlying quantification made explicit.

Computer-based systems have in recent years significantly enhanced analysts' ability to elicit decision makers' preferences and apply these preferences consistently in making decisions. The analytical hierarchy process (AHP) and the simple multi-attribute rating technique (SMART) are two increasingly widely. used procedures for which simplified software has been developed.

Copyright © National Academy of Sciences. All rights reserved.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Considering Multiple Points of View

Inevitably, at least in the initial stages of assessment and decision making, different decision makers or stakeholders will have different perspectives on the assessment and different preferences for possible actions to "improve" performance. Resolving these differences is not simply a technical problem but involves ethical questions as well.

Schulze and Kneese (1981) discuss the ethical aspects of such decision making, where many people bear the impact of resulting actions. Their context was deciding on levels of risk (a topic that receives further attention in this chapter), but their basic points apply more generally to infrastructure performance. They characterize four primary bases for making decisions: utilitarian, delivering the greatest good for the greatest number of people; egalitarian, measuring the well-being of the group (i.e., society) by the well-being of the worst-off person in that group; elitist, measuring the well-being of the group by the well-being of the best-off individual; and libertarian, an amalgam of principles, in that individual freedoms prevail except where others may be harmed.

Each of these four bases is used in infrastructure development and management, although seldom in a pure form. For example, locations of fixed-route transit lines (e.g., rail rapid transit and light rail) and stations may be characterized as typically utilitarian, selected to give access to the greatest possible number of people within an area. Drinking-water standards are egalitarian, set to ensure that no one is likely to contract an illness because of water-borne pathogens. Some people assert that U.S. highway policy is elitist regarding urban personal mobility, favoring those who can afford to own automobiles, although others note that highways often represent the lowest public component of cost for high mobility. Our general approach to the management of much of the infrastructure is essentially libertarian, although the lack of information about harm being done (e.g., air pollution being generated, safety hazards posed by driving above speed limits) can make these decisions seem faulty. In practical terms, taking care to involve stakeholders and applying a process that helps to ensure that their interests are effectively represented would significantly enhance confidence in infrastructure decision making.

DEALING WITH MULTIPLE JURISDICTIONS AND MODES

While different levels of government have well-defined roles in the planning, development, Operation, maintenance, and financing of urban infrastructure systems, the systems themselves do not respect jurisdictional boundaries. In transportation, state-owned and-operated high

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

ways, local streets, regional transit facilities and services, and airports serving a regional population can all be found within one local jurisdiction. Air and water pollution and transportation functions have multiregional and national span. Water distribution and wastewater collection systems often cross municipal borders, and solid waste collection increasingly requires regional approaches to recycling and managing disposal site capacity.

Similarly, there are a variety of issues that create interrelationships across infrastructure modes that can only be addressed through cooperation among the agencies responsible for each mode (i.e., transportation, water, wastewater, and solid waste). The potential impact on water quality of leachate from solid waste disposal and stormwater runoff from highways are examples of cross-mode issues.

As a result of these cross-jurisdiction and cross-mode issues, improving the performance of urban infrastructure will require significant cooperation across jurisdictions and across agencies with responsibility for different infrastructure modes. Regional agencies, special-purpose authorities and districts, joint-power agreements, and other voluntary or legislatively defined arrangements have been used to provide for regional and cooperative approaches. In addition, federal and state legislation funding infrastructure often requires multijurisdictional cooperation and involvement as well as broad public involvement as a condition for funding eligibility. Generally, requirements for multijurisdictional cooperation within an infrastructure mode have been more prevalent than requirements for cooperation across infrastructure modes. However, recent growth management legislation in a number of states has mandated coordination of development planning with the provision of all infrastructure required to support that development.

The committee found that legislation, organizational relationships, and other institutional factors are often the most challenging obstacles to effective performance assessment as well as management. **The committee recommends that responsible agencies undertake a critical self-assessment to determine the nature and extent of specific regulations, organizational relationships, jurisdictional limitations, customary practices, or other factors that may constitute impediments to adoption of the proposed infrastructure performance measurement framework and assessment process. Such a self-assessment could be conducted within the context of a specific infrastructure management problem or as a generic review, but it will necessarily involve time, money, and a concerted effort to motivate active community involvement with open, candid discussion. The assessment should conclude with explicit recommendations of institutional change that may be needed to enable a systemwide approach to management of infrastructure performance.**

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

While the existence of a variety of legal, regulatory, and financial mechanisms to encourage multijurisdictional cooperation is widespread, formal regional management is unlikely to be possible in many areas. A variety of less formal or comprehensive arrangements—for example, study commissions, cooperative regional councils, state planning programs, university-based regional research and policy institutions—may be established to accomplish many of the same ends. The strength of these arrangements and the degree to which regional approaches are followed and supported varies widely from area to area. The following factors are likely to influence the degree of multijurisdictional cooperation:

- degree to which regional agencies or approaches are legislatively defined;
- extent to which regional or multijurisdictional entities have independent taxing authority;
- regional vision for growth and development around which substantial consensus has been achieved and which can serve as a catalyst for joint action;
- severity of problems that can only be effectively addressed by joint action (i.e., congestion, solid waste disposal capacity, water supply and quality); and
- strong public and private sector leadership.

Within infrastructure modes, there are many examples of strong multi-jurisdictional approaches. Both Portland and the Twin Cities provided a number of cases of successful regionalism. However, as further improvements in infrastructure system performance are sought, it is likely that improving multijurisdictional cooperation will be a critical step. Cross-modal cooperation will also be critical to improving infrastructure performance and is less prevalent than multijurisdictional cooperation within a modal area. In many cases, improved cross-modal cooperation can be accomplished within a particular jurisdictional level by encouraging more coordination among departments or agencies with responsibilities for different infrastructure systems.

The committee observed that in some cases federal programs hinder or preclude cross-modal cooperation. Many capital grant regulatory programs are mode-specific. The committee recommends that federal infrastructure policies and regulations be reviewed in detail and revised as needed to accommodate local decision making processes and performance measurement frameworks. There are valid national interests in local infrastructure performance—for example, uniformly high standards of public health and safety—and local decisions should be made within the context of those interests. Nevertheless, one measure of federal policy effectiveness should be its sensitivity to local variations in objectives and subsequent performance assessment.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

A final important factor to be considered in measuring infrastructure system performance is the extent of the system being included in the analysis. While some aspects of performance may be related to a single facility, other dimensions of performance may require consideration of a group of interrelated facilities or an entire infrastructure system. For example, the structural capacity of a bridge can be measured and evaluated independently of other bridges or elements in the transportation system, but the traffic service provided by the same bridge can only be measured in the context of other elements of the highway system of which it is a part. Similarly, other improvements in transportation, water distribution, and wastewater collection facilities must be considered as part of the systems or subsystems affected by a change in one facility. While infrastructure professionals have always recognized the importance of "system effects," continued improvement in computer-based forecasting and simulation methods and new technology for measuring and monitoring system conditions have made more sophisticated approaches for assessing system performance widely available. Remote sensing, real-time monitoring, and network analysis and simulation models provide powerful new capabilities for measuring systemwide conditions and evaluating system changes.

UNCERTAINTY AND RISK IN INFRASTRUCTURE DECISION MAKING

Lack of sufficient information is a source of uncertainty in performance assessment and thus in decision making as well. Uncertainty is generally inherent in infrastructure performance assessment because information is never complete, the future can only be projected and not accurately predicted, and people's perceptions and judgments depend on the specific context in which they make a decision. Related to uncertainty is the notion of "risk," which involves both uncertainty and some kind of loss or damage that might be received if particular events do occur. This loss or danger, in turn, results from the interaction of "hazard," the source of danger (e.g., a toxic substance in water) and safeguards taken to protect against the hazard (e.g., water treatment to remove the substance). Risk is then the possibility of loss or injury or the probability of such loss.

Reliability, one of the three principal dimensions of performance, is essentially a measure of uncertainty. As such, this dimension has a crucial link with risk analysis. Risk itself may be selected as a component of effectiveness. Analysis of risk has become an important tool for setting policy in such areas as drug regulation and setting of environmental standards. Many of the principles and procedures used in risk analysis apply as well to all aspects of performance assessment. Hence, while the principles and methods of risk analysis are well beyond the scope of this study, the com

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

mittee agreed that the relationship of these topics to performance assessment warrants consideration.

Risk is never zero, but it can be small. Included under the heading "safeguards" is the idea of simple awareness. Awareness of hazard reduces risk. Thus, if we know there is a pothole in the road pavement around the comer, it poses less risk to us than if we drive around not knowing it is there. Generally, the assessed level of risk is influenced by awareness and perceptions.[4]

Analytical Methods

Attempts to deal analytically with uncertainty, risk, and reliability have frequently depended on complex applications of statistics and the mathematical theory of probability. Such methods are often useful but generally pose an ever-present danger of becoming overly sophisticated and unsupported by the availability of basic data. In addition, decision makers often cannot readily assimilate sophisticated statistical and probabilistic concepts in making actual choices among alternative courses of action.

Several methods have been developed, however, that can deal effectively with these concepts. The most successful applications tend to consider uncertainty in ways that fit naturally into common decision-making contexts, specifically the consideration of alternative scenarios. This approach too is no panacea, but if a manageable number of alternative scenarios can be agreed on and if some agreement can be reached regarding the assignment of relative probabilities of occurrence to these scenarios, then methods exist with which the information contained in multiple scenarios can be aggregated to the point of possible policy relevance.

Notable among these methods is regret theory, which had its origin as an alternative to the maximizing of expected utility as a basis for decision making (von Neumann and Morgenstern, 1947). "Regret" in this context refers to the disappointment, loss, or damage experienced when things do not occur as hoped or planned. Regret theory has to do with choosing courses of action that will control possible regret. The derision maker may forego some possibly greater benefit that might accrue if all goes well under one course of action, choosing instead some other course that has less potential for loss. For example, adopting a new process for sewage treatment may save money and reduce the concentration of plant nutrients in the effluent if the process works successfully, but it might force extensive dumping of raw sewage into the river if the process fails. Adopting the apparently more expensive but proven method is a decision to avoid regret.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

The Matter of Values

The overarching concerns in dealing with matters of uncertainty, reliability, and risk typically involve the question," How effective (e.g., safe, inexpensive, nonpolluting, nondisruptive) and reliable is effective and reliable enough?" Given that information is incomplete, ability to project outcomes is limited, and budgets for avoiding hazards or adopting safeguards are restricted, this question frequently arises in infrastructure decision making. In the end, the answer is generally a matter of values and cannot be resolved except through public discussion. **The committee found that community views inevitably become a part of the decision-making process, sometimes through public resistance when their views are inadequately considered. Efficiencies are to be gained when those views are solicited and considered early in the performance assessment process.**

For major decisions such as building new transit systems or waste disposal plants or imposing downtown parking controls or regional water-use restrictions, conflicts in values among various stakeholders are likely. In addition, values and preferences among difficult and unpleasant consequences may not be clearly defined or even well formed for many stakeholders. For example, many people in a region may have little basis for anticipating what will be involved in imposing traffic control measures to meet air pollution regulations. Their opinions will form after they experience the result and may lead to a call for very different ways to achieve stated objectives.

In our society, the answer to the question of "How effective... ?" is often determined in the political process not by scientific analysis. This is as it should be, but a number of factors make the political process somewhat cumbersome in determining acceptable performance. Regardless of how the decision is made, it is meant to represent how members of the public would individually make the acceptable performance decision. The collective decision is meant to reflect both the judgments and perceptions of each person and their values. Different individuals, however, may have widely varying judgments and perceptions and very diverse values. There are no simple solutions to the collective decision in such a case. Such decisions cannot please everyone. In any specific case, regardless of the level of acceptable risk resulting from the decision, many individuals can be quite disappointed and disagree with the alternative chosen.

A factor that worsens these problems is the high level of technical details that is involved in many performance decisions. In most cases, these details are either not known or not understood by members of the general public. In many of the cases, there is no way that the public can become completely informed. The fact is that one must be a specialist to

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

understand many of the technicalities, and there are enough technical details that no one individual can be a specialist in all aspects of an accept-able-risk decision. That the solution to an acceptable performance decision is not based solely on technical considerations complicates how such a decision should be made.

There are numerous ethical constraints on the entire decision process as well, as discussed in preceding sections of this chapter. Some of these constraints come directly from the charters of various governmental organizations, while others are historical in nature. Ethical constraints mean that there are certain alternatives and certain decision processes that simply cannot be followed. For example, a decision process that excludes the participation of the people who would bear substantial adverse impact (e.g., their farms would be taken to build a new airport) is unethical, although many such decisions were once made largely in secret. Since the ethics for our form of representative democracy are based on the consideration of the rights of individuals, such a decision process conflicts with our basic approach to government. Ethics are also involved with the political question of choosing the person or group that is responsible for making acceptable performance decisions. This responsibility carries with it the understanding that the collective decision process will be representative and consistent with our political ethics and social values and thus acceptable to the public. In order to determine acceptable performance with collective decisions, the decision process itself must be acceptable.

The Role of Regulatory Agencies

In many situations in our society, the general responsibility for making decisions about acceptable performance rests with a government regulatory agency. The legislative charters for these regulatory agencies, however, often state general, vague objectives for what the agency should do and seldom clearly indicate what the specific objectives of the agency should be or how to measure or achieve the regulatory objectives. These critical questions are left open for the agency to decide for itself, often outside of the effects of public participation.

In principle the regulatory agency provides a mechanism for the collective decisions that must be made on acceptable performance. The typical mechanism is that the regulators identify specific technical alternatives for achieving adequate performance. Then information on these risks for each of the alternatives is gathered and a recommendation or ruling is made. This ruling has the effect of either choosing the alternative or specifying guidelines by which it should be chosen by others. Rarely are the technical complications discussed here explicitly addressed to the level. of detail that might be useful. While systematic, scientific analysis has many appealing

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

features for aiding (but not replacing) the regulatory agency's decision making, exploiting this potential requires that the technical features and the social, political, and ethical aspects complicating the problem be explicitly recognized and addressed.

NOTES

1 For example, refer to Cohon (1978), Chankong and Haimes (1983), Zeleny (1982), Steuer (1986), and Szidarovsky (1986) for reviews of these methods.

2 These techniques often involve public meetings in which infrastructure professionals work with public participants to propose alternative ways of solving a particular problem, such as a highway route location. Such meetings were held in Baltimore's development of the East Boston Street improvement plan.

3 The field of multi-objective programming and decision making is represented by a substantial body of literature. A thorough review of this literature would be beyond the scope of the present study and of limited value to most participants in performance assessment. Good introductions to the principles and techniques suggested here may be found in Chankong and Haimes (1983), Cohon (1978), Steuer (1986), Szidarovsky (1986), and Zeleny (1982).

4 For example, see Cole and Withey, 1981.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

6

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

In brief, the Committee on Measuring and Improving Infrastructure Performance defined performance as the carrying out of a task or fulfillment of some promise or claim, and for infrastructure this means meeting the broad community's requirements for movement of goods and people, clean water supplies, waste disposal, and a variety of other services that contribute to economic and social activity, public health, a safe and pleasant environment, and a sustainably high quality of life. The committee undertook in this study to devise a systematic framework that can be used by decision makers for describing and assessing infrastructure performance. The committee recommends that using this framework and process will yield benefits of improved infrastructure performance. Infrastructure is a public asset that provides resources for pursuing the community's broad interests. Measuring infrastructure performance is an essential step toward making decisions aimed at achieving higher performance and improved use of these valuable assets. Systemwide management of performance is the mechanism for accomplishing this improvement.

The committee's several specific findings and conclusions are presented throughout the report and are summarized in Table 6-1. From its findings, the committee developed recommendations for how performance measurement might be most effectively implemented and used in managing the nation's infrastructure. These recommendations similarly are presented throughout the report and are summarized in Table 6-2 and discussed further here.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

At the end of the study, the committee finds that many unanswered questions remain as obstacles to performance measurement. There is work to be done by practitioners and researchers working together to improve methods for dealing with multi-objectives, performance measures, and stakeholders in a decision process. Better ways are needed for accounting for uncertainty and for multimodal infrastructure management. Data collection and management underlies virtually all aspects of performance measurement, and here too, improvements are needed.

HELPING DECISION MAKERS

The point of performance measurement is to help decision makers. For infrastructure, these decision makers include not only the engineers, architects, urban planners, public administrators, elected officials, and other professionals who develop and operate infrastructure but all the citizens, residents, and neighbors who own the infrastructure and occupy the areas that infrastructure serves. In seeking to describe and measure infrastructure performance, one is attempting to judge how well infrastructure is accomplishing the tasks set for the system or its parts by the society that builds, operates, uses, or is neighbor to that infrastructure.

As the committee has defined it, infrastructure that reliably meets or exceeds community expectations, at an acceptably low cost, is performing well. The committee recommends then that performance be measured in terms of its *effectiveness, reliability, and cost*. Measuring performance presents challenges of multiple expectations that the community holds for its infrastructure, the diverse views on whether those expectations are being met, costs that are distributed over time and paid from several sources, and the likelihood that community expectations and priorities may change during the typically long service life of infrastructure facilities. The specific performance measures used should be meaningful and appropriate to the needs of the decision makers, adequate and comprehensive to support thorough assessment, and have reasonable costs of measurement.

Performance is not the same as engineering "need" or the economist's concept of "demand," but rather represents an intersection of demand and supply, need, and capability, that can be established only within the context of community interests and priorities. Infrastructure may have other benefits or adverse impacts that are not aspects of its assessed performance, as when urban highways have been said to divide neighborhoods and destroy the sense of community needed to sustain older residential areas. However, such impacts may change community expectations and introduce new factors into the performance measurement.

Judging how well infrastructure is performing typically occurs in a public setting. Many people are likely to be involved, and reaching con

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 6-1 Summary of Principal Findings and Conclusions

Infrastructure Performance and its Measurement
1. Infrastructure comprises valuable assets that provide a broad range of services at national, state, and local levels. Its performance is defined by the degree to which the system serves this multilevel community's objectives. Identifying these objectives and assessing and improving infrastructure performance occur through an essentially political process involving multiple stakeholders.
2. Performance measurement, a technical component of the broader task of performance assessment, is an essential step in effective decision making aimed at achieving improved performance of these valuable assets.
3. Despite the importance of measurement, current practices of measuring comprehensive system performance are generally inadequate. Most current measurement efforts are undertaken because they are mandated by federal or state governments or as an ad hoc response to a perceived problem or the demands of an impending short-term project.
4. No adequate, single measure of performance has been identified, nor should there be an expectation that one will emerge. Infrastructure systems are built and operated to meet basic but varied and complex social needs. Their performance must therefore be measured in the context of social objectives and the multiplicity of stakeholders who use and are affected by infrastructure systems.
5. Performance should be assessed on the basis of multiple measures chosen to reflect community objectives. which may conflict. Some performance measures are likely to be location-and situation-specific, but others have broad relevance. Performance benchmarks based on broad experience can be developed as helpful guides for decision-makers.
6. The specific measures that communities use to characterize infrastructure performance may often be grouped into three broad categories: effectiveness, reliability, and cost. Each of these categories is itself multidimensional, and the specific measures used will depend on the location and nature of the problem to be derided.
Assessment Process
7. The performance-assessment process by which objectives are defined, specific measures specified and conflicts among criteria reconciled is crucial. It is through this process that community values are articulated and decisions made about infrastructure development and management.
8. Methodologies do exist for structuring decision making that involve multiple stakeholders and criteria, but experience applying these methodologies to infrastructure is limited.
9. Performance assessment requires good data. Continuing, coordinated data collection and monitoring are needed to establish benchmarking and performance assessment.
10. The subsystems of infrastructure—transportation, water, wastewater, hazardous and solid waste management, and others—exhibit both important physical interactions and relationships in budgeting and management. Effective performance management requires a broad systems perspective encompassing these interactions and relationships. Most infrastructure institutions and analytical methodologies currently do not reflect this broad systems perspective.
11. The long-term and sometimes unintended consequences of infrastructure systems, whether beneficial or detrimental, frequently go far beyond the physical installations themselves. Community views of these consequences become a part of the assessment and decision-making process.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

TABLE 6-2 Summary of Recommendations

1. Local agencies with responsibilities for infrastructure management should explicitly define a comprehensive set of performance measures and set aside funds sufficient to sustain an adequate performance measurement process. The measures selected should reflect the concerns of stakeholders about the important consequences of infrastructure systems and recognize interrelationships across infrastructure modes and jurisdictions. The committee's framework of effectiveness, reliability, and cost is a useful basis for establishing these measures.
2. While not every aspect of performance is quantifiable, attempts should be made to devise quantitative indicators of qualitative aspects of performance. Quantitative measures should then be used to develop benchmarks that policy makers responsible for assessing infrastructure performance can use for setting goals and comparing performance among systems, considering effectiveness, reliability, and costs (including actual expenditures as compared to budgets).
3. Recognizing that infrastructure performance cannot be managed if it cannot be measured, data should be collected on a continuing basis to enable long-term performance measurement and assessment.
   a. Each region with infrastructure decision-making authority should establish a system for continuing data collection to give performance assessment a more quantitative basis and enable longer term performance monitoring. Metropolitan areas with basic databases and modeling tools already in place should seek to integrate information on separate infrastructure modes into a uniform and accessible system, such that existing data sets are documented in consistent ways, within the context of relevant national data collection activities (e.g., federal Department of Transportation or EPA statistics).
   b. Federal agencies should assure that national data sets (i.e., those collected by or under the requirements of federal programs) are compatible (e.g., in geographic detail, time periods, and indexing), computerized, and made electronically accessible.
   c. All such performance data collection should be designed to facilitate benchmarking.
   d. New data collection activities should give priority to those functional areas where data currently are sparse (e.g., highway stormwater runoff characteristics, solid waste recycling reliability).
4. Responsible agencies should adopt infrastructure performance measurement and assessment as an ongoing process essential to effective decision making. The selected set of performance measures should be periodically reviewed and revised as needed to respond to changing objectives, budgetary constraints, and regulations.
5. Responsible agencies should undertake a critical self-assessment to determine the nature and extent of specific regulations, organizational relationships, jurisdictional limitations, customary practices, or other factors that may constitute impediments to adoption of the proposed infrastructure performance measurement framework and assessment process. Such a self-assessment could be conducted within the context of a specific infrastructure management problem or as a generic review, but necessarily will involve time, money, and a concerted effort to motivate active community involvement with open, candid discussion. The assessment should conclude with explicit recommendations of institutional change that may be needed to enable a systemwide approach to management of infrastructure performance.
6. Federal infrastructure policy and regulations should be revised as needed to accommodate local decision-making processes and performance measurement frameworks, within the context of valid national interests in local infrastructure performance. Federal policy effectiveness should be evaluated on the basis of its sensitivity to local variations in performance assessment.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

sensus can be difficult. Even when one person has clearly defined responsibility for making investment or operating decisions about some element of infrastructure, that person must be prepared for public scrutiny of his or her premises and conclusions. This is the context in which the committee envisions the framework to be most useful.

Performance assessment and management must be include the many individuals and entities who have a stake in performance. At a minimum, there are the providers of infrastructure services and users of those services. In addition, there are interested "nonusers" who are not providers or directly served by infrastructure but who nevertheless have a stake in its performance, such as residents of a metropolitan area who are exposed to the air pollution originating from highway vehicles. Variations in preferences from one local area to another are crucial to determining what aspects of infrastructure's services are more important and how resources can be allocated to achieve the performance locally judged to be "best." Because the goals and tasks set for infrastructure change from time to time and place to place, so will the dimensions of effectiveness by which stakeholders measure performance. The levels at which infrastructure is viewed must also be recognized, from the individual or household to the national or international scale. Political subdivisions can serve as a convenient designation for an increasingly broad perspective, and for some aspects of infrastructure they have functional significance. However, these subdivisions seldom are well matched to the technical bases on which infrastructure performance can most effectively be managed. Existing institutional relationships, often based on infrastructure functional modes (e.g., highway authorities, water utilities), also cannot handle well the multimodal interactions that determine infrastructure performance. Effective performance assessment will generally depend on cooperation among agencies at a multijurisdictional scale.

However, local values have overarching influence on all steps of the assessment process. Infrastructure is essentially a local concern, and even when the motivation for assessing performance comes from other levels, local values should be reflected in performance assessment.

While the multifunctional system of infrastructure is primarily a local matter, the federal government's interest and influence are substantial. Many federal programs that provide funds for facilities construction and equipment purchasing and other programs set standards and otherwise seek to ensure the safety and efficacy of infrastructure. A decade of debate among policy makers and professionals has failed to resolve questions about the overall condition of the nation's infrastructure, how much spending for infrastructure is reasonable, where the money will come from, and how spending should be allocated. In a period of record budget deficits, the incentives are clear to do better with the assets currently in

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

place. Current administration efforts to hold agencies accountable for achieving program results and generally to enhance the effectiveness of federal programs emphasize adoption of indicators of performance and measures of "outcomes," that is, the solid payoffs of federal effort. The committee's framework will be useful in this context as well.

Because the bases for managing infrastructure performance are not well developed, decisions sometimes are based on nothing more than whether the public has complained. Benchmarks or norms of performance are needed to apply comprehensively to all aspects of performance of any one type of infrastructure as well as to infrastructure as a system. Federal standards and standards-setting procedures are influential but may not foster "good" performance. Cities may be forced to incur costs meeting these standards and divert effort from other aspects of performance.

IMPROVING PERFORMANCE

The final result of assessment is a judgment that performance is adequate or good, needs improvement, or has improved following efforts to alleviate problems or realize a new vision for a community. An important value of performance assessment is in promoting and structuring interactions among stakeholders that lead to better understanding of community objectives and the role for infrastructure in realizing those objectives. This understanding is the basis for making good judgments on which decisions may be based. Even when a consensus is not reached, a structured approach offers the benefits of providing a framework for debate.

Debates arise because infrastructure services for any one user may be disruptive to the services others receive, and performance of the system as a whole will generally differ from what the individual user experiences. Because infrastructure development typically draws on broad sources of funding, a central issue in many decisions about infrastructure is the question of who benefits and who pays. Sometimes decisions are based primarily on whether federal funds are available, which may not support the best possible performance.

Communities make a distinction between infrastructure services that "must" be provided and what can be delivered if resources are made available. For example, some people will always choose to purchase bottled waters, even if the public water supply is basically healthful and meets requirements of the federal Safe Drinking Water Act. The choice is available to those who can afford the higher cost, but the system's performance may or may not be "good."

Achieving the balance that defines "good" infrastructure performance—between the capability of the multifunctional system and the demands of its users—requires public motivation and broad input to deci

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

sion making. Reducing the demand or load on the system may be equally as effective as increasing the system's ability to meet higher demand, or even more so. When infrastructure professionals seek to make such judgments, there is potentially some tension between public perception and opinion on the one hand and professionals acting as experts on the other.

There is likely to be continuing tension as well between national interests and local priorities in the setting of goals for infrastructure. It is probably unavoidable in a diverse nation that some areas will find that objectives set for clean air or highway safety impose burdens on local businesses or households that seem too great for the benefits realized. Resolving these tensions will always pose a major challenge for the political process.

For major decisions, such as building new transit systems or waste disposal plants or imposing downtown parking controls or regional water-use restrictions, conflicts in values among various stakeholders within the community are likely as well. In addition, these values and resulting preferences may not be clearly defined or even well formed for many stakeholders.

In all these settings, the assessment process proposed here and the strategies for improving performance will influence the way in which opinions form. The final decisions about how best to undertake performance improvement often will be resolved in the political process, not by scientific analysis. The committee recommends its assessment framework as an aid to exploration, discussion, and effective resolution of the complex issues of infrastructure performance, but it will be up to the users of these tools to make the difficult choices.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

REFERENCES

Adams, J.L. 1991. Flying Buttresses, Entropy, and O-rings: The World of an Engineer. Cambridge, Massachusetts: Harvard University Press.

APWA (American Public Works Association). 1991. Public Works Management Practices. Kansas City, Missouri: AWPA.

Berry, B.J.L., and Q. Gillard. 1977. The-Changing Shape of Metropolitan America: Commuting Patterns, Urban Fields, and Decentralization Processes, 1960-1970. Cambridge, Massachusetts: Ballinger.

Chankong, V., and Y.Y. Haimes. 1983. Multiobjective Decision Making: Theory and Methodology, North-Holland Series in System Science and Engineering 8. New York: North-Holland.

Choate, P., and S. Walter. 1981. America in Ruins: Beyond the Public Works Pork Barrel. Washington, D.C.: Council of State Planning Agencies.

Cohon, J.L. 1978. Multi-objective Programming and Planning. New York.: Academic Press.

Cole, G.A., and S.B. Withey. 1981. Perspectives on Risk Perceptions. Risk Analysis 1(2):143-163.

Keeney, R.L. 1988. Structuring Objectives For Problems of Public Interest. Operations Research 36 (3):396-405.

NCPWI (National Council on Public Works Improvement). 1988. Fragile Foundations: A Report on America's Public Works. Washington, D.C.: U.S. Government Printing Office.

NRC. 1987. Infrastructure for the 21st Century: Framework for a Research Agenda. Committee on Infrastructure Innovation, National Research Council. Washington, D.C.: National Academy Press.

NRC. 1993. In Our Own Backyard: Principles for Effective Improvement of the Nation's Infrastructure. A. Grant and A. Lemer, eds. National Research Council. Washington, D.C.: National Academy Press.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Schulze, W.D., and A.V. Kneese. 1981. Risk in benefit-cost analysis. Risk Analysis 1(1):81-88.

Steuer, R.E. 1986. Multiple Criteria Optimization. New York: John Wiley & Sons.

Szidarovsky, F. 1986. Techniques for Multiobjective Decision Making in Systems Management. Amsterdam: Elsevier.

TRB. 1985. Highway Capacity Manual. Special Report 209. Transportation Research Board, National Research Council. Washington, D.C.: TRB.

USACE. 1991. National Economic Development Procedures Manual: Overview Manual for Conducting National Economic Development Analysis. U.S. Army Corps of Engineers. Army Engineer Institution for Water Resources, Fort Belvoir, Virginia: Institute for Water Resources.

USACE. 1993. Framing the Dialogue: Strategies, Issues and Opportunities. The Federal Infrastructure Strategy Program, IWR Report 93-FIS-1. U.S. Army Corps of Engineers. Army Engineer Institution for Water Resources, Fort Belvoir, Virginia: Institute for Water Resources.

U.S. Congress Joint Economic Committee. 1984. Hard Choices: A Report on the Increasing Gap between America's Infrastructure Needs and Our Ability to Pay for Them. Washington, D.C.: U.S. Government Printing Office.

Von Neumann, J., and O. Morgenstern. 1947. Theory of Games and Economic Behavior, 2nd ed. Princeton, New Jersey: Princeton University Press.

Zeleny, M. 1982. Multiple Criteria Decision Making. New York: McGraw-Hill.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix A

THE COMMITTEE ON MEASURING AND IMPROVING INFRASTRUCTURE PERFORMANCE

STATEMENT OF TASK[1]

The committee will meet as a whole and in working panels to identify key issues and make recommendations regarding how infrastructure (transport, water resources, and waste management) performance is characterized; how standards of performance are set; standards' positive and negative influence on effective service provision; and impacts of these matters on the cost-effectiveness of infrastructure. Focusing on urban infrastructure, committee members, with staff support, will review previous work in the field, prepare workable multimodal definitions of performance, and recommend a common framework for infrastructure management and improving infrastructure performance. One or more reports will be prepared to present the committee's work and recommendations. The committee's work is sponsored by the USACE, Institute for Water Resources, as part of a program to explore the federal role in national infrastructure policy.

[1] This Statement of Task is presented to the committee at project initiation and filed with the National Research Council records office as Committee Records Form #1.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix B

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS AND STAFF

JARED L. COHON, (Chair), Ph.D., is Dean of the School of Forestry and Environmental Studies and Professor of Environmental Systems Analysis at Yale University. Formerly Vice Provost for Research and Professor of Geography and Environmental Engineering at the Johns Hopkins University, Dr. Cohon is expert in mathematical optimization and water resource systems analysis, and has previously served on several NRC committees.

W. BRUCE ALLEN, Ph.D., is Vice-Dean, Wharton School, Director, Undergraduate Division, Professor of Public Policy and Management, Regional Science and Transportation Director, Wharton Transportation Program, University of Pennsylvania. He works in the field of freight transportation demand/economics, transportation, and commodity flows.

L. G. (GARY) BYRD, a consulting engineer and NAE member, has over 35 years of experience in design, management systems, and policy-related studies of highways and bridges throughout the United States and abroad. Mr. Byrd served from 1984 to 1986 as interim director of the Strategic Highway Research Program. Formerly senior vice president and director, Wilbur Smith and Associates, and manager of Byrd, Tallamy, MacDonald and Lewis, a division of Wilbur Smith and Associates, Mr. Byrd is active in local and national activities of both the American Society of Civil Engineers and the Transportation Research Board, and is a past member of the Board of Consultants of the Eno Foundation for Transportation, Inc.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

RANDALL W. EBERTS, Ph.D., is Executive Director of the W. E. Upjohn Institute for Employment Research. Formerly Assistant Vice President and Economist, Federal Reserve Bank of Cleveland, his work as a research economist and policy analyst spans labor and infrastructure investment issues related to urban and regional development. He has published a number of key papers on the impact of infrastructure investment and condition on economic output.

HUGH ELLIS, Ph.D., Professor in the Department of Geography and Environmental Engineering of the Johns Hopkins University, conducts research and teaches classes on air pollution and systems analysis.

HAROLD T. GLASER, Vice President of Montgomery Watson, Inc., has over 16 years of experience in environmental engineering with emphasis on design and evaluation of water and wastewater facilities, computer aided design, automated mapping and facilities management, and analysis, design, and development of engineering and scientific computing systems. Mr. Glaser was a member of the Civil Engineering Research Foundation's team that in 1991 conducted an assessment of Japan's infrastructure technology and research efforts.

GARETH GREEN, M.D., is Associate Dean for Professional Education and Director, Master of Public Health Programs at the Harvard School of Public Health.

FRANNIE HUMPLICK, Ph.D., is an Infrastructure Economist with the World Bank.

ELLIS L. JOHNSON, Ph.D. is Coca-Cola Professor of Industrial and Systems Engineering at the Georgia Institute of Technology and a member of the NAE. Previously he spent 25 years on the Research Staff at IBM's T.J. Watson Research Center, where he managed the Optimization Center, worked on several applications projects and software, and was named an IBM Fellow in 1990. At Georgia Tech, Dr. Johnson is co-director of the Logistics Engineering Center.

LANCE A. NEUMANN, Ph.D., is President of Cambridge Systematics, Inc., and a specialist in transportation systems analysis, investment programming, policy studies, and large-scale system planning.

VIET NGO is the developer of the Lemna System for using aquatic plants for wastewater treatment, and President and CEO of the Lemna Corporation, Inc. His work, serving as chief engineer for design, construction management, and operation of numerous large and small wastewater treatment projects, emphasizes integration of visual, technical, and environmental concerns.

SERGIO RODRIGUEZ, AICP, is Assistant City Manager for the City of Miami and the Director of the Planning Department and the Building and Zoning Department. He is an active member of the American Institute of Certified Planners, American Planning Association, Planning

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Accreditation Board, South Florida Planning and Zoning Association, National Association of Cuban Architects, and American Institute of Architects.

GEORGE ROWE, 1993-1994 President of the American Public Works Association, recently retired as Director of Public Works, City of Cincinnati, Ohio. For his work as a leader in that city's successful programs to revitalize its public works infrastructure, he was in 1989 named one of the Top Ten Public Works Leaders of the Year by the American Public Works Association.

KENNETH I. RUBIN, Ph.D., President and co-founder of Apogee Research, Inc., is broadly experienced in engineering, economic, and financial analysis of environmental infrastructure and environmental management programs.

IRAJ ZANDI, Ph.D., is Professor of Systems and the National Center Professor of Resource Management at the University of Pennsylvania. He is editor and publisher of the Journal of Resource Management and Technology and editor of the Journal of Pipelines.

STAFF

ANDREW C. LEMER, Ph.D., is President of the MATRIX Group, Inc., and has served as a consultant to many private and government agencies, including the World Bank, the U.S. Department of Transportation, and the National Institute of Building Sciences. Formerly Division Vice President with PRC Engineering, Inc., he headed multidisciplinary teams responsible for developing the master plans for Abuja, the new federal capital on Nigeria, and Batam Center new town in Indonesia. He was a member of the Civil Engineering Research Foundation's teams that conducted reviews of infrastructure technology and research in Japan (1991) and western Europe (1993). Dr. Lemer served as Director of the Building Research Board, 1988-1993, and was a Loeb Fellow at Harvard University's Graduate School of Design for 1992-1993.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix C

PARTICIPANTS AT THE INITIATING COLLOQUIUM

WASHINGTON, D.C. APRIL 14-15, 1993

DR. JARED LEIGH COHON, Dean, School of Forestry and Environmental Studies, Yale University

MR. EZRA D. EHRENKRANTZ, Chair, Architecture and Building Science, New Jersey Institute of Technology

DR. JAMES P. GOULD (NAE), Partner, Mueser Rutledge Consulting Engineers

MR. ALBERT A. GRANT, Chairman, Consultant, Potomac, Maryland

DR. FRANNIE HUMPLICK, Infrastructure Economist, The World Bank

DR. ELLIS LANE JOHNSON, IBM Fellow, T.J. Watson Research Center, Coca-Cola Professor, Georgia Institute of Technology

DR. JOSEPH PERKOWSKI, Manager, Advanced Civil Systems Research & Development, Bechtel National Inc.

MR. JOHN RAMAGE, Vice President, CH2M Hill, Inc.

MR. SERGIO RODRIGUEZ, AICP, Assist. City Manager/Planning Director, City of Miami

DR. PETER P. ROGERS, Professor, Division of Applied Sciences, Harvard University

MR. GEORGE ROWE, P.E., Director of Public Works, City of Cincinnati

DR. KENNETH I. RUBIN, President, Apogee Environmental

MR. RICHARD L. SIEGLE, P.E., Director of Facilities Services, Smithsonian Institution

DR. RAYMOND L. STERLING, Associate Professor and Director, Underground Space Center, University of Minnesota

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

DR. EUGENE Z. STAKHIV, Chief, Policy Division, Institute for Water Resources, U.S. Army Corps of Engineers

MS. NANCY HUMPHREY, Senior Program Officer, Transportation Research Board

DR. ROBERT SCHAFRIK, Director, National Materials Advisory Board

DR. ANDREW C. LEMER, Ph.D., Director, Building Research Board

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix D

MEETING PARTICIPANTS

DECEMBER 16-17, 1993, BALTIMORE, MARYLAND

GEORGE G. BALOG, Department of Public Works
FELICIA BONSALL, Office of Director Staff, Information
JAMES CAUSEY, Traffic Division
WALTER CHRYSAM, Water Facilities Division
RALPH CULLISON, Environmental Services Division
LINDA S. DAVIS, Bureau of Water and Wastewater
CAROLYN DORSEY, Office of Director Staff, Land Conveyance
MICHAEL GIBBS, Department of Planning
ROBERT B. MACLEOD, Office of Director Staff, Boards & Commissions
FRED MARC, Highways Division
JOHN MARTIN, Wastewater Facilities Division
EDWARD F. MAY, Solid Waste Disposal Division
SARANE MCHUGH, Office of Director Staff, Fascal (Capital)
VANESSA PYATT, Office of Director Staff, Information Services
JEANNE ROBINSON, Solid Waste Collection Division
JERRY SILHAN, Utility Engineering Division
DAISY SKUPIEN, Department of Public Works
AMAR SOKHEY, Facilities Engineering
NICK STEPHEN, Utility Maintenance Division
KENNETH STRONG, Office of Director Staff, Recycling
ORVILLE A. SWAFFORD, Bureau of Solid Waste
M. FAYSAL THAMEEN, Office of Director Staff, Interstate

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

FEBRUARY 17-18, 1994, PORTLAND, OREGON

G.B. ARRINGTON, Tri-Met
BILL BACH, Port of Portland
SANDY BOARDMAN, Office of Transportation
EARL BLUMENAUER, City of Portland
ANDY COTUGNO, METRO
STEVE DOTTERRER, Office of Transportation
LARRY DULLY, Portland Development Commission
CINDY GAULKE, Office of the Commissioner
DAVID LOEHMAN, Port of Portland
DOUGLAS MORGAN, Public Administration Program
BOB POST, Tri-Met
VIC RHODES, City of Portland
PAUL SHIREY, Portland Development Commission
EDWARD TENNEY, Montgomery Watson
FELICIA TRADER, Office of Transportation

MAY 11-13, 1994, MINNEAPOLIS, MINNESOTA

RICHARD T. BRAUN, Metropolitan Airports Commission
CATHERINE BROWN, University of Minnesota
NATALIO DIAZ, Metropolitan Council
MARCEL JOUSEAU, Metropolitan Council
WILLIAM REES MORRISH, University of Minnesota
LEE W. MUNNICH, JR., Hubert H. Humphrey Institute of Public Affairs
RAYMOND L. STERLING, University of Minnesota
GORDON VOSS, Consultant
EDWARD J. WARN, City of St. Paul
LYLE WRAY, Citizens League

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix E

SELECTED BIBLIOGRAPHY ON INFRASTRUCTURE PERFORMANCE

This bibliography includes selected references addressing principles, methodology, policies, and historical background related to infrastructure performance definition, measurement, and management. The bibliography has been assembled to provide background and bases for discussion in the Building Research Board's study of infrastructure performance, focusing on infrastructure serving urban and metropolitan regions, as considered in the NCPWI 1988 report *Fragile Foundations*: transport (highways, transit, and airports), water (water supply and water resources), and waste (wastewater treatment, solid waste, and hazardous waste). Sewerage and stormwater management are included with wastewater treatment and solid waste. In addition references are included that provide perspective on issues of economic development, urban growth and decay, environmental quality, and technological evolution that have particular bearing on performance.

BACKGROUND: ECONOMIC DEVELOPMENT, URBAN GROWTH AND DECAY, ENVIRONMENTAL QUALITY, TECHNOLOGICAL EVOLUTION, AND PUBLIC PERCEPTION

Aitcin, C., and A. Neville. 1993. High-Performance Concrete Demystified. Concrete International (American Concrete Institute) 15(1):21-26.

Ausubel, J.H., and R. Herman, eds. 1988. Cities and Their Vital Systems: Infrastructure Past, Present, and Future, Washington, D.C.: National Academy Press .

Azad, B., and M. Jacobs. 1986. Infrastructure Finance and Institutions, A Review of International Experience. Report No. 47. Multiregional Planning Staff, Department of Urban Studies and Planning, Massachusetts Institute of Technology. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Bacon, J. 1990. Redefining infrastructure: a midwestern city's experience. Public Management 72 (4):14.

Beito, D., and B. Smith. 1990. The formation of urban infrastructure through non-governmental planning: The private places of St. Louis, 1869-1920. Journal of Urban History 16 (3):263-303.

Browne, L.E. 1991. The role of services in New England's rise and fall: Engine of growth or along for the ride? New England Economic Review July/August:27-44.

Civil Engineering Research Foundation. 1993. High-Performance Construction Materials and Systems: An Essential Program for America and Its Infrastructure. Executive Report (Report 93-5011.E). Washington, D.C.: Civil Engineering Research Foundation.

Cohen, J.M., and P. Monteiro. 1991. Durability and integrity of marble cladding: A state-of-the-art review. Journal of Performance of Constructed Facilities 5(2):113-124.

Cronon, William. 1991. Nature's Metropolis: Chicago and the Great West. New York: W. W, Norton.

Dalton, L.C. 1989. The limits of regulation, evidence from local plan implementation in California. Journal of the American Planning Association 55(2):51-168.

Daniels, G.H., and M.H. Rose, eds. 1982. Energy and Transport: Historical Perspectives on Policy Issues. Beverly Hills, California: Sage Publications.

Derby, S.L. and R.L. Keeney. 1981. Risk analysis: Understanding "How safe is safe enough?" Risk Analysis 1(3):217-224.

Dimitriou, H. T. 1991. An integrated approach to urban infrastructure development. A review of the Indonesian experience. Cities August:193-208.

Eberts, R.W. 1986. Estimating the Contribution of Urban Public Infringe to Regional Growth. Working Paper 8610. Cleveland, Ohio: The Federal Reserve Bank.

Eberts, R.W. 1990. Cross Sectional Analysis of Public Infrastructure and Regional Productivity Growth. Working Paper 9004. Cleveland, Ohio: The Federal Reserve Bank.

Eberts, R.W., and K. Deno. 1991. Public infrastructure and regional economic development: A simultaneous equations approach. Journal of Urban Economics 30:329-343.

Eberts, R.W. 1990. Some Empirical Evidence on the Linkage Between Public Infrastructure and Local Economic Development, in Herzog and Schlottman, eds. Industry Location and Public Policy. Knoxville: University of Tennessee Press.

Eisner, R. 1991. Infrastructure and regional economic performance: Comment. New England Economic Review September/October 1991:47-58.

Enhance Reinsurance Company. 1991. Infrastructure Investment, An Historical Overview. New York: Enhance Financial Services Group, Inc.

Gakenheimer, R. 1989. Infrastructure shortfall: The institutional problems. Journal of the American Planning Association 55(1):14-23.

Grabowski, H.G., and J.M. Vernon, in cooperation with the Committee on Technology and International Economic and Trade Issues of the Assembly of Engineering, National Research Council and the Office of the Foreign Secretary, National Academy of Engineering. 1979. The Impact of Regulation on Industrial Innovation. Washington, D.C.: National Academy Press.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Groak, S. 1990. Robust Technologies: The decline of robust technologies in the building industry. Building Research Practice 18(3):162-168.

Green, H., compilers. 1991. Public Works Management Practices. Chicago: American Public Works Association.

Guile, B., and J.B. Quinn, eds. 1988. Managing Innovation: Cases from the Services Industries. Washington, D.C.: National Academy Press.

Henderson, H. 1994. Light Rail, Heavy Costs. Planning 60(5):8-13. Chicago: American Planning Association.

Hulten, C.R., and R.M. Schwab. 1991. Is America really on the road to ruin? The Public's Capital 2 (4):6-7.

Isacson, O., J. Ewetz, and G. Lundgren. 1986. The Effects of State Support on Industry and on the Market for Solar Heating, Heat Pumps and Heat Storage. Stockholm, Sweden: Swedish Council for Building Research.

Kazis, R. 1989. Rags to riches? One industry's strategy for improving productivity. Technology Review August/September:42-53.

Keeler, T.E. 1975. Automobile Costs and Final Intermodal Cost Comparisons: (preceded by summary of final results). The Full Costs of Urban Transport; Pt. 3. Institute of Urban and Regional Development, University of California, no. 21. Berkeley: Institute of Urban and Regional Development, University of California.

Knack, R.E. 1988. America in ruins? Not quite. Planning February:9-14.

Krier, J.E. 1977. Pollution and Policy: A Case Essay on California and Federal Experience with Motor Vehicle Air Pollution, 1940-1975. Berkeley: University of California Press.

McDowell, B.D. 1992. Public works for tomorrow. Intergovernmental Perspective 18(3):23-25.

McFadden, R.D. 1991. Report faults M.T.A. on pace of capital repair program. The New York Times. October 18, 1991:B1, B2.

Menendez, A. 1991. Access to Basic Infrastructure By the Urban Poor. Economic Development Institute: Policy Seminar Report No. 28. Washington, D.C.: The World Bank.

Montgomery, W.D. 1989. Lessons from the Past, Opportunities for the Future: The Changing Role of Public Investment in Economic Growth. Remarks to the Colloquium on the Nation's Infrastructure Policy, Washington, D.C. November 17.

Munnel, A.H. 1990. How does public infrastructure affect regional economic performance? New England Economic Review September/October:11-33.

National Council on Public Works Improvement. 1988. Fragile Foundations: A Report on America's Public Works. Final Report to the President and Congress. Washington, D.C.: U.S. Government Printing Office.

NRC. 1991. Enabling Technologies for Unified Life-Cycle Engineering of Structural Components. National Materials Advisory Board, National Research Council. NMAB-455. Washington, D.C.: National Academy Press.

NRC. 1987. Concrete Durability: A Multibillion-Dollar Opportunity. National Materials Advisory Board, National Research Council. Washington, D.C.: National Academy Press.

Platt, H.L. 1983. City Building in the New South: The Growth of Public Service in Houston, Texas 1830-1910. Philadelphia: Temple University Press.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Schemenner, R.W. 1983. Every factory has a life cycle. Harvard Business Review March/April:121-128.

Sharbatoghlie, A. 1986. The Decline of Infrastructure and the Federal Government Response. Prepared for the Economic Development Administration, U.S. Department of Commerce. Report No. 39. Multiregional Planning Staff, Department of Urban Studies and Planning, Massachusetts Institute of Technology. Cambridge, Massachusetts: Massachusetts Institute of Technology.

Snickars, F. 1989. Effects of Infrastructure Provision on Urban Economic Development. Infrastructure and Building Sector Studies:29 Working Paper from CERUM 1989.

Stover, M.E. 1987. The role of infrastructure in the supply of housing. Journal of Regional Science 27:255-268.

Subcommittee on Economic Goals and Intergovernmental Policy of the Joint Economic Committee, U.S. Congress. 1984. Hard Choices: A Report on the Increasing Gap Between America's Infrastructure Needs and Our Ability To Pay for Them 98-164. Washington, D.C.: U.S. Government Printing Office.

Svedinger, B. 1991. The Technical Infrastructure of Urban Communities: A Survey of Current Knowledge. Stockholm Sweden: Swedish Council for Building Research.

Thurmond, J. 1989. An argument for investing in infrastructure. Public Management 71(6):13-14.

USACE. 1992. Infrastructure Reports: Summaries. U.S. Army Corps of Engineers Fort Belvoir, Virginia: Institute for Water Resources.

U.S. Congress, Congressional Budget Office. 1991. How Federal Spending for Infrastructure and Other Public Investments Affects the Economy. Congress of the United States, Congressional Budget Office.

U.S. Congress, House of Representatives. 1990. Infrastructure Needs Assessments and Financial Alternatives. Hearing Before the Subcommittee on Policy Research and Insurance of the Committee on Banking, Finance and Urban Affairs. May 8. Serial No. 101-117.

U.S. Congress, Office of Technology Assessment. 1991. Delivering the Goods: Public Works Technologies, Management, and Financing. OTA-SET-477. Washington, D.C.: U.S. Government Printing Office.

Warner, S.B. 1978. Streetcar Suburbs: The Process of Growth in Boston, 1870-1900, 2nd ed. Publications of the Joint Center for Urban Studies. Cambridge, Massachusetts: Harvard University Press.

Working Group on Infrastructure. 1993. An Infrastructure Proposal for Jobs, the Environment and Performance. Washington, D.C.

GENERAL PERFORMANCE DEFINITION, MEASUREMENT, AND MANAGEMENT

ASTM. 1986. Building Performance: Function, Preservation, and Rehabilitation. A symposium sponsored by ASTM Committee E-6 on Performance of Building Constructions, Bal Harbour, Florida. ASTM special technical publication 901 . Philadelphia, Pennsylvania: ASTM Incorporated.

ASTM. 1990. Performance of Buildings and Serviceability of Facilities. STP 1029. Philadelphia, Pennsylvania: ASTM Incorporated.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

The Construction Industry Institute. 1986. Evaluation of Design Effectiveness. University of Texas at Austin: The Construction Industry Institute.

Diewert, W.E. 1986. The Measurement of the Economic Benefits of Infrastructure Services. Lecture Notes in Economics and Mathematical Systems 278. Berlin, New York: Springer-Verlag.

Frank, J.E., and M.K. Falconer, 1990. The measurement of infrastructure capacity: theory, data structures, and analytics. Computers, Environment, and Urban Systems 14 (4):283-297.

Godwin, S.R., and G.E. Peterson. 1984. Guide to Assessing Capital Stock Condition. Guides to Managing Urban Capital, Vol. 2. Washington, D.C.: The Urban Institute Press.

Gullo, T., D. Parham, and G.E. Peterson. 1984. The Role of Standards in Infrastructure Management. Washington, D.C.: The Urban Institute Press.

Kasimer, J.H. 1988. Reducing and defending against building failure claims. The Construction Specifier October:36-37.

Kilgore, R.T., M.N. Zatz, and G. K. Young. 1991. The Relationship Between Standards and the Performance of Infrastructure. Springfield, Virginia: GKY and Associates, Inc.

Kirby, J.G., and J. M. Grgas. 1975. Estimating the Life Expectancy of Facilities. Technical Report P-36. USA Construction Engineering Research Laboratory. Springfield, Virginia: National Technical Information Service.

Mahmassani, H.S., and S. Peeta. 1992. Network Performance Under System Optimal and User Equilibrium Dynamic Assignments: Implications for ATIS. Austin, Texas: University of Texas. For presentation at 72nd Annual Meeting of the Transportation Research Board, Washington, D.C.

Masters, L., ed. 1985. Problems in Service Life Prediction of Building and Construction Materials. Boston: Martinus Nijhoff Publishers.

Masters, L. 1986. Prediction of service life of building materials and components. Materiaux et Constructions 19(114):417-422.

Morris, P.W.G. 1988. Lessons in managing major projects successfully in a European context. Technology in Society 10:71-98.

Neely, E.S. 1991. Building Maintenance and Repair Data for Life Cycle Cost Analyses: Architectural Systems. USACERL Special Report P-91/17. U.S. Army Corps of Engineers.

O'Connell, G.B. 1989. Rate your city—Here's how! (rating of a city's infrastructure) Public Management 17(6):7-10.

Peterson, G.E., M.J. Miller, S.R. Godwin, and C. Shapiro. 1984. Guide to Benchmarks of Urban Capital Condition. Guides to Managing Urban Capital, Vol. 3. Washington, D.C.: Urban Institute.

Ronnen, U. 1991. Minimum quality standards, fixed costs, and competition. RAND Journal of Economics 22(4):490-504.

Terleckyj, N.E. 1985. Measuring Economic Effects of Federal R&D Expenditures: Recent History with Special Emphasis on Federal R&D Performed in Industry. Paper commissioned for a workshop on The Federal Role in Research and Development, National Academy of Sciences. Washington, D.C.

NRC. 1992. Data for Decisions: Requirements for National Transportation Policy Making. Special Report 234. Transportation Research Board, National Research Council. Washington, D.C.: National Academy Press.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

Ventre, F.T. 1983. Documentation and Assessment of the GSA/PBS Building Systems Program: Background and Research Plan. NBSIR 83-2662. Washington, D.C.: U.S. Department of Commerce.
The World Bank. 1991. Research Proposal: Homing Indicators for Policy-Making: An Extensive International Survey. Urban Development Division. Infrastructure and Urban Development Department.

TRANSPORT

Appleyard, D. 1964. The View from the Road. Published for the Joint Center for Urban Studies of the Massachusetts Institute of Technology and Harvard University by the M.I.T. Press, Massachusetts Institute of Technology.
Black, A. 1989. Analysis of trends in transit work trips. Journal of the American Planning Association 55(1):38-43.
Drake, R.W., and D. W. Carter. 1990. Impacts of Standardized vs. Non-Standardized Bus Fleets. Report No. 17. Transportation Research Board, National Research Council, Washington, D.C.
Fundakowski, R.A. 1991. Video image processing for evaluating pavement surface distress. A digest of report. NCHRP Research Results Digest 181:1-4.
Harrison, D. 1978. The impact of transit systems on land use patterns in the pre-automobile era. Discussion paper presented to Harvard University, Department of City and Regional Planning; D78-21. Cambridge, Massachusetts: Harvard University, Department of City and Regional Planning.
Kellett, J.R. 1969. The Impact of Railways on Victorian Cities. London: Routledge and Kegan Paul.
Lerner, A.C. 1992. Measuring Performance of Airport Passenger Terminals. Transportation Research 26A(1):37-45.
McCallum, W.R. 1963. Highway Bond Financing, An Analysis: 1950-1962. U.S. Department of Commerce, U.S. Bureau of Public Bonds. Washington, D.C.: U.S. Government Printing Office.
McShane, C. 1979. Street pavements. Journal of Urban History May:296-78.
Memmott, J.L., M.K. Chui, and W.F. McFarland. 1993. CBO's Assessment of Transportation Infrastructure Needs: Critique and Extension. College Station, Texas: Texas Transportation Institute, Texas A&M University.
NRC. 1986. Measures of Marine Container Terminal Productivity. Improving Productivity in U.S. Marine Container Terminals. Marine Board, National Research Council. Washington, D.C.: National Academy Press.
Olson, D.J. 1992. Governance of U.S. Public Ports: A Preliminary Survey of Key Issues. Washington, D.C.: Marine Board Port Governance Roundtable.
Organization for Economic Co-operation and Development. 1980. Urban Public Transport: Evaluation of Performance. A report prepared by an OECD Road Research Group. Paris: OECD.
Parkinson, T. 1992. Rail transit performance. Transportation Research Record 1361:47-52.
Peterson, D.E. 1987. Pavement management practices. Synthesis of Highway Practice 135. Transportation Research Board, National Research Council. Washington, D.C.: TRB

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Rose, M.H. 1979. Interstate: Express Highway Politics, 1941-1956. Lawrence: Regents Press of Kansas.

Seely, B.E. 1987. Building the American Highway System: Engineers as Policy Makers. Technology, and Urban Growth Series. Philadelphia: Temple University Press.

Transportation Research Board. 1987. Assessing pavement maintenance needs. Transportation Research Record 1109. Washington, D.C.: TRB.

Transportation Research Board. 1987. Measuring Airport Landside Capacity. Special Report 215. Washington, D.C.: TRB.

Transportation Research Board. 1985. The evolution of transportation planning. Transportation Research Record 1014. Washington, D.C.: TRB.

U.S. Congress. House Committee on Public Works and Transportation. 1991. Our Nation's Surface Transportation System: Enhancing Intermodalism and U.S. Global Competitiveness for the 21st Century. Our Nation's Transportation and Core Infrastructure hearings before the Committee on Public Works and Transportation, House of Representatives, 102nd Congress, first session, February 20, 1991. Washington, D.C.: U.S. Government Printing Office.

Westley, G.D. 1978. Planning the Location of Urban-Suburban Rail Lines: An Application of Cost-Benefit and Optimal Path Analysis. Cambridge, Massachusetts: Ballinger Publishing Company.

WATER SUPPLY AND WATER RESOURCES

Abernethy, C. L. 1986. Performance Measurement in Canal Water Management: A Discussion. ODI/IIMI Irrigation Management Network 86/2d. London: Overseas Development Institute.

Agthe, D.E., and R.B. Billings. 1987. Equity, price elasticity, and household income under increasing block rates for water. The American Journal of Economics and Sociology 46(3):273-286.

Blake, N.M. 1956. Water for the Cities: A History of the Urban Water Supply Problem in the United States. Maxwell School series 3. Syracuse, New York: Syracuse University Press.

Button, K.J., and D.W. Pearce. 1989. Infrastructure restoration as a tool for stimulating urban renewal—the Glasgow Canal. Urban Studies 26(6):559-572.

Dunne, T. 1978. Water in Environmental Planning. San Francisco: W. H. Freeman.

Fiering, M.B. 1978. Standards, Optimality and Resilience in Water-Resource Management: Final Report. Cambridge, Massachusetts.: Division of Applied Sciences, Harvard University.

Freund, A.P. 1993. Statement by Adrian P. Freund, AICP, on behalf of the American Planning Association, before a hearing of the Subcommittee on Water Resources of the Committee on Public Works and Transportation, U.S. House of Representatives, on Reauthorization of the Federal Water Pollution Control Act. Washington, D.C.: American Planning Association.

Grigg, N.S. 1986. Urban water infrastructure: planning, management, and operations. New York: John Wiley & Sons.

Lazaro, T.R. 1979. Urban hydrology: A Multidisciplinary Perspective. Ann Arbor, Michigan: Ann Arbor Science Publishers.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Mays, L.W. 1991. Water distribution system infrastructure analysis. Water Resources Update 86:20-22.

Peiser, R. 1988. Calculating equity-neutral water and sewer impact fees. Journal of the American Planning Association 54(1):38-48.

Petts, G.E. 1985. Rivers and Landscape. Baltimore, Maryland: Edward Arnold.

Reisner, M. 1987. Cadillac Desert: The American West and Its Disappearing Water. New York: Penguin Books.

Rogers, P.P. 1978. The Interaction Between Urbanization and Land: Quality & Quantity in Environmental Planning and Design; Water Resources: Water Quantity and Water Quality. NSF/RA-780427. Cambridge, Massachusetts: Landscape Architecture Research Office, Graduate School of Design, Harvard University.

Walesh, S.G. 1989. Urban Surface Water Management. New York: John Wiley & Sons.

WASTE MANAGEMENT

Center for Urban Policy Research. 1976. Solid Waste Planning in Metropolitan Regions. New Brunswick, New Jersey: Rutgers University.

Chertow, M.R. 1989. Garbage Solutions: A Public Official's Guide to Recycling Alternative Solid Waste Management Technologies. Washington, D.C.: U.S. Conference of Mayors.

Ferguson, B.K. 1987. On-Site Stormwater Management: Applications for Landscape and Engineering. Mesa, Arizona: PDA Publishers Corp.

Francis, C.W., and S.I. Auerbach, eds. 1983. Environment and Solid Wastes: Characterization, Treatment, and Disposal. Boston: Butterworths.

Goldfarb, W., and B. King. 1982. Urban stormwater runoff: the legal remedies. Real Estate Law Journal 11(1):3-46.

Gehr, M. 1977. Solid Waste Management: A Selected and Annotated Bibliography. Exchange Bibliography—Council of Planning Librarians. Monticello, Illinois: Council of Planning Librarians.

General Electric Company. 1976. Solid Waste Management: Technology Assessment. New York: Van Nostrand Reinhold Co.

Jenkins, R.R. 1993. The Economics of Solid Waste Reduction: The Impact of User Fees. New Horizons in Environmental Economics. Aldershot, Hants, England; Brookfield, Vermont: E. Elgar Publishing.

Lynch, K. 1990. Wasting Away. San Francisco: Sierra Club Books.

Melosi, M.V. 1981. Garbage in the Cities: Refuse, Reform, and the Environment, 1880-1980. Environmental History Series; No. 4. College Station, Texas: Texas A&M University Press.

Menell, P.S. 1991. Optimal Multi-tier Regulation: An Application to Municipal Solid Waste. Cambridge, Massachusetts: Center for Science & International Affairs, John F. Kennedy School of Government.

Muhich, A.J. 1968. 1968 National Survey of Community Solid Waste Practices, Preliminary Data Analysis [by] A.J. Muhich, A.J. Klee, [and] P.W. Britton. Public Health Service publication, No. 1867. Cincinnati: Environmental Control Administration, Solid Wastes Program.

Copyright © National Academy of Sciences. All rights reserved.

Neal, H.A. 1987. Solid Waste Management and the Environment: The Mounting Garbage and Trash Crisis. Englewood Cliffs, New Jersey: Prentice-Hall.

Nelson, A.C., and G.J. Knaap. 1987. A theoretical and empirical argument for centralized regional sewer planning. Journal of the American Planning Association 53(4):479-487.

Organization for Economic Co-operation and Development. Waste Management Policy Group. 1981. Economic Instruments in Solid Waste Management. Paris: Organization for Economic Co-operation and Development.

Peterson, J. 1979. The impact of sanitary reform upon American urban planning, 1840-1890. Journal of Social History 13:95-96.

Pollock, C. 1987. Mining Urban Wastes: The Potential for Recycling. Worldwatch paper 76. Washington, D.C.: Worldwatch Institute.

Reid, D. 1991. Paris Sewers and Sewermen: Realities and Representations. Cambridge, Massachusetts: Harvard University Press.

Schultz, S.K., and C. McShane. 1978. To engineer the metropolis: sewers, sanitation, and city planning in late-nineteenth century America. Journal of American History 65:389-411.

Tarr, J.A. 1979. The separate vs. combined sewer problem: a case study in urban technology design choice . Journal of Urban History 5:308-339.

Tchobanoglous, G. 1977. Solid Wastes: Engineering Principles and Management Issues. New York: McGraw-Hill.

U.S. Congress. Office of Technology Assessment. 1989. Facing America's Trash: What Next for Municipal Solid Waste? Summary. Washington, D.C.: Government Printing Office.

U.S. Environmental Protection Agency. 1990. A Catalog of Hazardous and Solid Waste Publications. Office of Solid Waste and Emergency Response. Washington, D.C.: EPA.

U.S. Office of Solid Waste and Emergency Response. Environmental Protection Agency. 1990. Characterization of Municipal Solid Waste in the United States: 1990 Update. Washington, D.C.: EPA.

U.S. Office of Solid Waste. Municipal Solid Waste Task Force. 1989. The Solid Waste Dilemma: An Agenda for Action: Final Report of the Municipal Solid Waste Task Force, Office of Solid Waste, United States Environmental Protection Agency. Washington, D.C.: EPA.

U.S. Office of Solid Waste, Office of Policy, Planning, and Evaluation, Environmental Protection Agency. 1990. Sites for Our Solid Waste: A Guidebook for Effective Public Involvement. Washington, D.C.: EPA.

Wanielista, M.P. 1993. Stormwater Management. New York: John Wiley & Sons.

Wilson, D.G., ed. 1977. Handbook of Solid Waste Management. New York: Van Nostrand Reinhold Co.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Appendix F

GLOSSARY

Several professional disciplines share interest in issues of infrastructure performance. Each discipline adopts terminology that may have precise or generally accepted meaning for members of that discipline, but may differ from the terminology of other disciplines or common usage. In conducting their study, the committee frequently used the following terms and found it helpful to agree on their definitions. (Terms shown in *italics* in definitions are themselves defined.)

Assessment. Judgment of the adequacy, acceptability, or value of behavior or characteristics of a system; generally based on observation or *measurement*.

Benefit. Impact or result of an action or event related to building, operating, maintaining, or using infrastructure, not necessarily related to the tasks that infrastructure is intended to accomplish; may be positive or negative, in the latter case, may be termed *disbenefit*.

Benchmark. A basis for comparison derived from past behavior or characteristics of a system or comparable systems, against which current behavior or characteristics of the system may be judged; not a *standard*, although standards may be adopted from benchmarks.

Community. A group or several groups of people and institutions drawn together by common interest in development and management of *infrastructure*; may include local, regional, state, and national perspectives.

Cost. See *system cost*

Copyright © National Academy of Sciences. All rights reserved.

Measuring and Improving Infrastructure Performance
http://www.nap.edu/catalog/4929.html

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Design lifetime. The period of time, assumed as a basis for making feasibility studies and design decisions, during which a facility of element is anticipated to provide service; for infrastructures, typically 15 to 50 years. Not necessarily the same as *service life* or *economic life*.

Dimension). (of effectiveness A single aspect of *effectiveness* that can be discussed and assessed with minimal reference to other aspects (e.g., traffic congestion on a highway versus the stormwater runoff from that highway)—in principle, linked directly to goal or task set for infrastructure.

Disbenefit. A negative *benefit; an* adverse impact or consequence.

Economic life. The period of time over which infrastructure is expected to repay its full *cost*. Often determined by financial factors as well as technical.

Effectiveness. A multidimensional component of *performance*; the degree to which infrastructure accomplishes the tasks set for it by its owners, users, neighbors, and society-at-large.

Evaluation. *Assessment* in which tradeoffs may be made among disparate and generally incommensurable *measures*, especially for determining preference among several complex alternative courses of action.

Indicator. A *measure*, but often not very specific in its information about effectiveness; for example, the color red is frequently used as an indicator of high temperature, which is in turn a measure of heat energy or risk of burning.

Infrastructure. Not specifically defined in this study; generally used in this report to refer to facilities and their operations and the operating and management institutions that provide water, remove waste, facilitate movement of people and goods, and otherwise serve and support other economic and social activity or protect and enhance environmental quality. Refer to cited references for further discussion (e.g., NRC, 1987; NCPWI, 1988; NRC, 1993).

Level of service. A *measure of effectiveness*; frequently used for transportation infrastructure and most well developed for highway and street traffic capacity analysis (e.g., see TRB, 1985).

Measure, measure of effectiveness. A sign, symbol, or statistic (typically numerical) that people understand to convey information about how well infrastructure is accomplishing its tasks, typically for a single *dimension* of *effectiveness*; may be based on some generally used scale (e.g., water or traffic volumes) or defined relative to a *benchmark* (e.g., observed throughput as a fraction of theoretical maximum throughput) or *standard* (e.g., observed pollution concentration as a fraction of the level allowable under law). A specific *indicator*.

Copyright © National Academy of Sciences. All rights reserved.

Measurement. Structured observation and documentation of one or more aspects of the behavior or characteristics of a system. Implies no *assessment* or *evaluation*.

Performance. The degree to which infrastructure provides the services that the community expects of it; a function of *effectiveness, reliability*, and *cost*.

Reliability. A component of *performance*; the likelihood that infrastructure effectiveness will be maintained over an extended period of time; the probability that service will be available at least at specified levels throughout the *design lifetime* of the infrastructure system.

Service life. The time over which infrastructure actually provides service to users; a result of operating and maintenance practices. Often exceeds *economic life and design lifetime*.

Stakeholder. An individual or group within the *community*, having a particular interest, perspective, goals, or objectives that bear on how *infrastructure performance is* assessed.

Standard. A basis for comparison and assessment of behavior or characteristics of a system, established by law, regulation, common practice, or consensus; may be derived from past behavior or characteristics of comparable systems. Compare *benchmark*.

System. An assemblage or combination of elements forming a complex whole, e.g., the highways in a particular region; the assemblage of all the individual functional modes (e.g., water supply, transportation) of *infrastructure* that together serve and support economic and social activity or protect and enhance environment of a city or region.

System cost. A component of *performance*; the resources required build, operate, and maintain infrastructure; typically measured in monetary terms. In appropriate context, also termed simply cost. Not the same as *user cost*.

User cost. A dimension of *effectiveness*. The monetary or other direct expenditures that users must make to gain access or use infrastructure services; not the same as *cost*.

About this PDF file: This new digital representation of the original work has been recomposed from XML files created from the original paper book, not from the original typesetting files. Page breaks are true to the original; line lengths, word breaks, heading styles, and other typesetting-specific formatting, however, cannot be retained, and some typographic errors may have been accidentally inserted. Please use the print version of this publication as the authoritative version for attribution.

Copyright © National Academy of Sciences. All rights reserved.