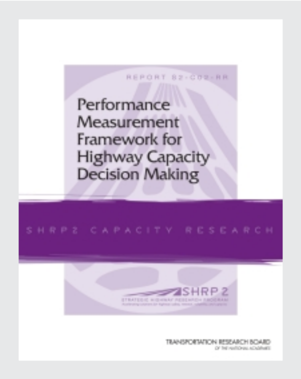

Performance Measurement Framework for Highway Capacity Decision Making

DETAILS

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Transportation Research Board

The Second

STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP 2 REPORT S2-C02-RR

Performance Measurement Framework for Highway Capacity Decision Making

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SUBJECT AREAS

Planning and Administration • Energy and Environment • Highway and Facility Design

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The Second Strategic Highway Research Program

America's highway system is critical to meeting the mobility and economic needs of local communities, regions, and the nation. Developments in research and technology—such as advanced materials, communications technology, new data collection technologies, and human factors science—offer a new opportunity to improve the safety and reliability of this important national resource. Breakthrough resolution of significant transportation problems, however, requires concentrated resources over a short time frame. Reflecting this need, the second Strategic Highway Research Program (SHRP 2) has an intense, large-scale focus, integrates multiple fields of research and technology, and is fundamentally different from the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway research industry for half a century.

The need for SHRP 2 was identified in *TRB Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life,* published in 2001 and based on a study sponsored by Congress through the Transportation Equity Act for the 21st Century (TEA-21). SHRP 2, modeled after the first Strategic Highway Research Program, is a focused, time-constrained, management-driven program designed to complement existing highway research programs. SHRP 2 focuses on applied research in four focus areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

SHRP 2 was authorized in August 2005 as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The program is managed by the Transportation Research Board (TRB) on behalf of the National Research Council (NRC). SHRP 2 is conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provides for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the Federal Highway Administration, U.S. Department of Transportation, or the American Association of State Highway and Transportation Officials.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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SHRP 2 STAFF

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The research reported on herein was performed by Cambridge Systematics, Inc., supported by High Street Consulting Group, Ross & Associates, Spy Pond Partners, and Jim Shrouds. Hugh Louch, Cambridge Systematics, Inc., was the Principal Investigator. The other authors of this report are Virginia Smith Reeder of Cambridge Systematics, Inc. and Joe Crossett of High Street Consulting Group. The authors acknowledge the contributions to this research from Steve Pickrell, Erik Cempel, Tracy Clymer, Randall Halvorson, and Joanne Potter of Cambridge Systematics; Anna Williams and Tim Larson of Ross & Associates; and Frances Harrison of Spy Pond Partners.

FOREWORD

Stephen J. Andrle, *SHRP 2 Chief Program Officer, Capacity*

This report describes a performance measurement framework that supports the collaborative decision-making framework (CDMF) for additions to highway capacity being developed under the SHRP 2 Capacity research program. Five broad areas of performance are identified: transportation, environment, economics, community, and cost. Under these headings, 17 performance factors are identified and each is linked to key decision points in the CDMF. While the purpose of the performance measurement framework is to establish a systematic approach, the emphasis of the research was on less-developed areas of measurement, such as climate change, ecosystems, environmental health, archeological and cultural resources, and travel time reliability. Measures for each factor are provided along with a discussion of data needs and data gaps. A companion web tool was also developed. The web tool is intended to be a permanent and dynamic resource and will be updated as additional SHRP 2 and other research is completed. The measures were assembled from interviews, case studies documented in the report, other SHRP 2 work, and the literature on the subject.

Measures of transportation system performance are integral to demonstrating the need for highway capacity expansion, evaluating alternative solutions, and monitoring performance. To date, agencies have generally had greatest success with operations and maintenance-related measures, such as pavement quality, bridge deficiency, and safety; and capacity-related measures such as volume-to-capacity ratio, or level-of-service rating. Well-established data collection and analysis techniques have reinforced the use of these and similar measures as tools for decision making.

The public continues to be concerned about the impacts of adding highway capacity and demands even broader analysis. Now measures addressing environmental justice, greenhouse gas emissions, infrastructure vulnerability to climate change, air toxics exposure, consistency with land use and other plans, community cohesion, and visual quality are of interest. Transportation agencies generally do not have well-developed data collection and analysis techniques in these new areas. Even selecting the measures is a matter for public input and debate. Some of the challenges that must be overcome include performance measure design, data collection, target setting, and interpretation and use of results. Better approaches are needed for quantifying transportation system performance in non-traditional areas. The ability to better understand system-level performance in terms of economic, mobility, accessibility, safety, environmental, community, and social considerations leads to more collaborative decision making during system planning and project development.

Performance measures have communication value as well as analytical value because a better collective understanding is achieved of the transportation problem being addressed. Each constituency can see a measure that relates to its concerns, and each constituency can better see the concerns of others. A fundamental principle of SHRP 2 Capacity research is that the right people must be at the table at the right time with the right information. Performance measures that stakeholders help to select that speak to their concerns is a big step toward making the best transportation decision and delivering it with a minimum of delay.

The report devotes a chapter to each of the five performance areas, covering for each the background literature, key findings, identification of performance factors, a selection of measures for each factor, and case study references. For example, under the "community cohesion" factor, five measures are suggested:

- Number of homes and businesses to be relocated
- Forecasted change in walking trips
- Change in travel times to neighborhood points of congregation
- Key pedestrian routes severed
- Key pedestrian routes reconnected.

Appendices provide detailed write-ups of case studies conducted as part of the project and a discussion of data sources, data gaps, and high-value data investment opportunities.

The information in this report will prove valuable to decision makers in state departments of transportation; planning, operations, and environmental review staff in all transportation agencies; environmental resource agencies; nongovernmental conservation organizations; metropolitan planning organizations; elected officials; and the public.

CONTENTS

Executive Summary

Transparency and accountability in transportation decision making are basic to building credibility with stakeholders and the public. Performance measures that are relevant to system users and useful to transportation professionals can provide these conditions and for that reason, performance measurement is a key component of the collaborative decision-making framework (CDMF) being developed by the second Strategic Highway Research Program (SHRP 2) Capacity focus area. The CDMF identifies key decision points (KDP) in four phases of transportation decision making: long-range planning, corridor planning, programming, and environmental review and permitting.

Project C02, *A Systems-Based Performance Measurement Framework for Highway Capacity Decision Making,* supports this effort by creating a state-of-the-art performance measurement framework that individual transportation agencies and other public agencies can adapt to support the needs of both agencies and stakeholders in the decision-making process for major transportation capacity projects. The framework focuses on providing performance-related measures that enable departments of transportation (DOTs) to address the challenges most common in the expansion of highway capacity, as identified in the CDMF's key decision points. It emphasizes performance measurement as a tool to place individual projects within a system context.

The work completed for the performance measurement framework was based on several key supporting research efforts, each of which is detailed in the final report, including:

- Development of the overall performance measurement framework, based on the broad application of performance management at transportation agencies in the United States;
- A review of the literature on performance measurement, with a focus on 'nontraditional' areas such as the environment, community, and travel time reliability;
- Interviews with transportation agencies to determine the extent to which they are using performance measures in various areas identified in the literature; and
- Targeted case studies to identify performance measures and applications at specific transportation and other agencies.

Collaborative Decision Making Context

The CDMF defines specific key decision points in project development. Specific performance measures, data, and tools can be linked to these key decision points to help ensure that the best information is available as transportation agencies make decisions about projects. Figure ES.1 summarizes the relationship between the collaborative decision-making framework and the performance measurement framework.

The CDMF helps address the process for developing transportation projects that add capacity, including questions about the roles of specific agencies in supporting the process.

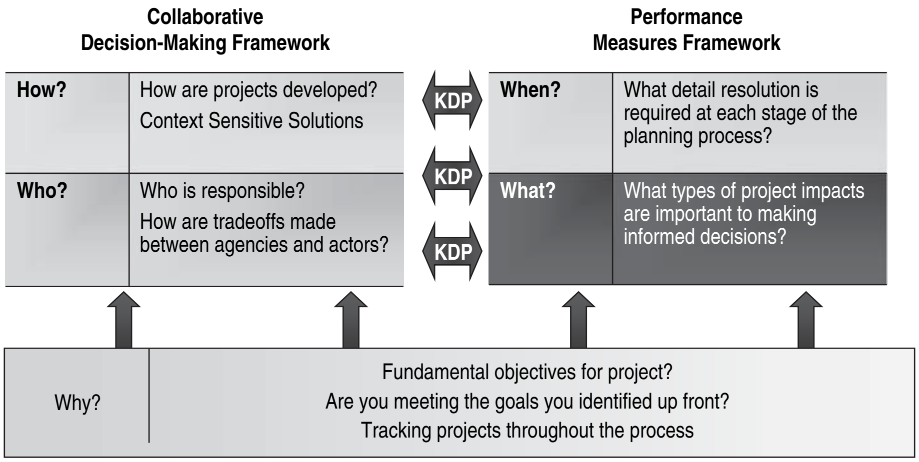


Figure ES.1. Relationship between performance measurement framework and collaborative decision-making framework.

The performance measurement framework helps address two related questions:

- What types of project impacts are important to making informed decisions? The framework organizes and defines a set of measure concepts that can be tailored to a specific transportation agency context for reviewing major capacity projects, and others; and
- What detail resolution is required at each stage of the planning process? The framework explains how the measures can be used in long-range planning, programming, environmental review, and permitting. As a project develops through these phases, the availability of data and level of detail will change.

Performance Measurement Framework

The performance measurement framework is organized around a set of five broad topics (transportation, environment, economics, community, and cost) and 18 performance factors within these areas. These performance factors capture the key areas that may be impacted by a potential project. Table ES.1 identifies the planning factors identified by topic.

Each of these major topic areas is summarized below.

Transportation	Environment	Economics	Community	Cost
Mobility	Ecosystems, Habitat, and Biodiversity	Economic Impact	Land Use	Cost
Reliability	Water Quality	Economic Development	Archeological and Cultural Resources	Cost-Effectiveness
Accessibility	Wetlands		Social	
Safety	Air Quality		Environmental Justice	
	Climate Change			
	Environmental Health			

Table ES.1. SHRP 2 C02 Performance Factors

Transportation

In evaluating major capacity expansion projects, impacts on the movement of people and goods over that system are among the most common considerations. The performance measures framework identifies four categories for evaluating the impact of capacity-adding projects on transportation system performance:

- **Mobility.** Mobility refers to the ability of the transportation system to facilitate efficient movement of people and goods. Mobility typically addresses recurring congestion that results when traffic volumes approach or exceed available roadway capacity. Mobility measures do not capture the implications of the location of the congestion compared to desired destinations, but instead simply highlight the extent of congestion in comparison with free-flow conditions.
- **Reliability.** Reliability refers to the ability of users of the system to predict the amount of time it takes to make trips on the system. Reliability typically addresses nonrecurring congestion that results from traffic incidents (crashes, breakdowns, special events, weather, and construction). Factors that impact reliability include things such as route redundancy, incident response, and incident rates.
- **Accessibility.** Accessibility refers to the ability of the transportation system to connect people to desired destinations through the spatial analysis of residential population, employment centers, and other service or recreation opportunities. Accessibility differs from mobility in that the measures can consider all modes, and focus specifically on the congestion on those roadways that inhibit key travel for a particular population or trip type.
- **Safety.** Safety refers to the ability for users of the system to reach their destination safely on any given trip. This is typically measured through the record of crashes or incidents along a particular roadway or at a specific intersection. Although transportation projects often focus exclusively on safety, the focus in this framework is on the safety impacts of highway capacity expansion projects.

Table ES.2 summarizes the measures identified in each of the transportation areas. Additional detail is available in the report.

Environment

Environmental impacts of highway capacity projects have traditionally been addressed through the National Environmental Policy Act (NEPA) process, parallel state processes, and related federal and state regulations. These efforts focus on minimizing the impacts of new or expanded infrastructure through modifications to specific alignments and mitigation of those impacts that cannot be avoided. These efforts have typically focused narrowly on the transportation right-of-way, but recent federal and state efforts are shifting how environmental factors are addressed by: 1) considering the relationship between transportation and the natural environment more broadly, with a focus on protecting and enhancing quality environmental areas, rather than mitigating the impacts of specific projects; and 2) understanding and addressing environmental factors starting at the earliest stages of project development, especially long-range planning. Six performance factors have been identified within the environmental area of the framework, including:

- **Ecosystems, Habitat, and Biodiversity.** Highways can cause direct loss of habitat resulting from road construction; fragmentation and isolation of existing habitats; obstacles that limit migration and dispersal and create smaller, more inbred populations; and animal/vehicle collisions resulting in wildlife mortality and a serious safety concern for the traveling public. Recent work in this area focuses on the way an entire ecosystem works, rather than narrowly examining impacts on individual species.

Factor	Measures
Mobility	**Recurring Delay –** Difference between the actual time required by motorist to traverse a roadway segment and the unconstrained time.
	Trip Travel Time – Time required for a motorist to complete a trip from its origin to its destination.
	Travel Time Index – Ratio of the actual travel time for a trip compared to the unconstrained travel time.
	Volume to Capacity Ratio – Actual number of vehicles using a roadway segment relative to the number of vehicles it is designed to handle over a fixed time period.
	Level of Service – Qualitative letter grade of highway operating conditions from A (unconstrained travel) to F (severe congestion).
	Vehicle Miles Traveled – Number of vehicles traveling a specified portion of the highway network over a set time multiplied by its length in miles.
	Mode Share – Number of percent of transportation system users using non-SOV travel means (e.g., transit, bicycle, high-occupancy vehicle travel).
Reliability	**Reliability Index –** A measure of the additional time (in minutes, percent extra time, etc.) that trips take under congestion conditions relative to uncongested or 'normal' conditions.
	On-Time Trip Reliability – Share of trips between a specific origin and destination with travel times below a designated threshold of time.
	Incident Duration – Average time elapsed from notification of an incident to incident clearance.
	Crash Analysis – Identification of high crash locations by roadway segment.
Accessibility	**Job Accessibility –** Number of jobs within a reasonable travel time for a region's population.
	Destination Accessibility – Average travel time to major regional destinations.
	Labor Force Accessibility – Number of residents within reach of the region's employers.
	Market Accessibility – Average travel time to market centers.
	Environmental Justice Accessibility Impact – Relative jobs, destinations, labor force, and market accessibility for environmental populations versus the general population.
Safety	**Safety –** Crashes per hundred million vehicle-miles traveled.
	Crashes – Absolute number of crashes over time (e.g., per year).

Table ES.2. Transportation Area Measures, by Factor

- **Water Quality.** Considering the effects of highway capacity on water resources can help protect water resources and also ecosystems, biodiversity, wildlife habitat, and endangered or sensitive species that rely on healthy aquatic ecosystems. Water quality protection has historically been considered after project sites have been selected, but there is growing support for considering water quality protection much earlier in the planning process, before environmental and permitting processes are required. Recent work in this area focuses on a watershed approach that takes into considerations the functions of individual water bodies in an overall system.
- **Wetlands.** Wetlands are complex ecosystems that, depending on their type and on circumstances within a watershed, can improve water quality, provide natural flood control, diminish droughts, recharge groundwater aquifers, and stabilize shorelines. They are vital to both water quality and ecosystem function. Regulated by the Clean Water Act, wetlands can be addressed by the watershed and ecosystem approaches identified under the water quality and ecosystems factors. There has been a recent move toward the consideration of wetlands quality, and not solely quantity, in project planning and programming processes.
- **Air Quality.** Clean Air and transportation legislation has required the integration of the transportation and air quality planning processes since 1970. This integration is intended to ensure that transportation decisions are consistent with the air quality goals for a region. Current requirements include the transportation conformity process, which requires that projects within transportation improvement programs do not exceed air quality standards for an area.

- **Climate Change.** Climate change should be addressed both in terms of transportation impacts on the climate, and the potential impacts of climate change on transportation infrastructure. Research suggests that climate change will significantly impact transportation infrastructure through rising sea levels and related changes.
- **Environmental Health.** Although the topic of environmental health is broad, this framework focuses on the issue of mobile source air toxics, a by-product of vehicle emissions and a well-documented contributor of cancer and noncancer human health problems. This is an emerging area of research.

Table ES.3 summarizes the measures identified in each of the environmental factors. Additional detail is available in the report.

Factor	Measures
Ecosystems, Habitat, and Biodiversity	**Loss of Habitats –** Impact of transportation construction on degradation in quality and quantity of land essential to the survival of target plant or animal species.
	Natural Resource Plan Consistency – Consistency between natural resource plans and transportation project plans.
	Animal-Vehicle Collisions – Impact of transportation projects on the number and characteristics of collisions between animals and vehicles.
	Losses of Native Plants – Impact of transportation construction on the quality and quantity of native plant communities.
Water quality	**Water Quality Protection Areas –** Impact of transportation construction on priority water quality protection area.
	Hydromodification – Impact of transportation construction on water quality due to the alteration of water bodies by transportation projects.
	Losses of Riparian and Floodplain Areas – Impact of transportation construction on the quality, quantity, location, and functioning of the areas adjacent to the affected water bodies that strongly influence water quality.
	Water Resource Plan Consistency – Consistency between water resources and watershed management plans and transportation project plans.
	Construction-Related Water Quality Impacts – Impacts on water quality due to highway construction.
	Water Quality Standards Compliance – Consistency of transportation project-related water quality impacts with water quality standards.
	Highway Runoff – Change in water quality due to added highway capacity.
	Impervious Surface – Impact on watershed water quality due to additional buildings, roads, and other impervious surfaces built as a result of added transportation capacity.
Wetlands	**Ratio of Wetland Acres Taken and Replaced –** Annual impact of transportation construction on statewide amount of wetlands lost compared to new wetlands built.
	Losses of High-Quality Wetlands – Impact of transportation construction on high-value wetlands.
	Wetlands Plan Consistency – Consistency between wetlands plans and transportation project plans.
Air Quality	**Transportation Conformity –** Comparison of actual on-road transportation-related emissions in air quality non-attainment or maintenance region versus desired level of emissions identified in state's air quality plan to ensure national ambient air quality standards are met or exceeded.
	Carbon Monoxide and Particulate Matter Concentrations – Contribution of projects to localized CO or PM violations in nonattainment and maintenance areas.
Climate Change	**Greenhouse Gas Emissions –** Total amount of transportation-related pollutants that cause global climate change.
	Infrastructure Vulnerability – Susceptibility of transportation infrastructure to damage caused by environmental hazards associated with global climate change.
	Carbon Sequestration – Net change in quantity of carbon stored in biomass located along transportation corridors as a result of construction and operations-related vegetation management practices.
Environmental Health	**Air Toxics Concentrations –** Impact of transportation construction on concentrations of mobile source air toxics.
	Air Toxics Exposure – Proximity of vulnerable populations potentially affected by mobile source air toxics.

Table ES.3. Environment Area Measures, by Factor

Economic

Transportation investments have significant potential economic benefits and impacts that are often considered in analyses of potential capacity expansion projects. Transportation infrastructure plays a vital role in the economy at local, regional, and national levels and investments in this infrastructure provide benefits through improved accessibility, reduced travel times, and similar changes. Infrastructure investments also can disrupt economic activities by restricting access to businesses during construction or taking local businesses as part of right-of-way acquisition. The framework considers two economic factors:

1. **Economic Impacts –** These impacts include monetized user benefits such as travel-time savings and fuel and nonfuel cost savings, improvements in reliability, and safety benefits.
2. **Economic Development –** Economic development captures the broader economic benefits that can accrue as a result of transportation investment. This factor includes productivity effects driven by supply chain improvements, accessibility benefits, and more general macroeconomic impacts such as regional economic output and employment.

The SHRP 2 Capacity focus area is conducting research into economic factors and potential performance measures as part of the C03 project, *Interactions between Transportation Capacity, Economic Systems, and Land Use merged with Integrating Economic Considerations in Project Development.* Measures for this section of the framework will be developed as part of the C03 effort.

Community

Highway capacity projects can have both positive and negative impacts on the physical and social characteristics of a local community. Because the valued characteristics of a community are often subjective, the impacts (both positive and negative) must be evaluated collaboratively, with input provided from residents, local business owners, and other interested stakeholders. The measurement of community impacts should be grounded in local and regional land use and transportation plans that establish a clear vision for a community. Although there are several potential ways to classify community impacts, the following four categories are used to differentiate among the key concepts in this part of the framework:

- **Land use.** Land use impacts include changes in land cover and vegetation, changes in the use of land from natural to human uses, and changes in the type of use (e.g., residential, commercial, industrial, agricultural). The change in land use can be reflected in the environmental quality of the land, the type of human use, and the intensity of use. Highway capacity projects can impact land use through direct physical impacts on the land, or indirect impacts resulting from new levels of mobility and accessibility.
- **Archeological, Historical, and Cultural Resources.** Communities often have an interest in preserving their past to maintain a sense of history, offer educational opportunities, and support research. Highway capacity projects can threaten preservation efforts directly, by impacting historic, cultural, and archeological sites, or indirectly, by changing the usage around these sites to impact the access and experience of a visit to the site.
- **Social.** Impacts on the social aspect of communities range from aesthetics and noise to displacement and fragmentation. Highway capacity projects can impact these factors through the built form of the infrastructure or the effects of construction or operation of the facility.
- **Environmental Justice.** In addition to evaluating overall transportation, economic, environmental and community impacts, transportation agencies must consider the differential impacts of the various factors considered in this framework on traditionally disadvantaged

Factor	Measures
Land Use	**Transportation Land Consumption –** Amount of land converted to transportation uses. **Induced Development Land Consumption –** Amount of land developed for nontransportation uses as a result of the project. **Consistency of Induced Land Consumption with Land Use Plan –** Extent to which anticipated induced growth impacts are consistent with local and regional plans for growth. **Support of Project for Growth Centers –** Project serves designated growth centers or growth policy areas. **Local-Regional Plan Consistency –** Consistency of local land use policies with regional transportation-land use vision.
Archeological, Historical, and Cultural Resources	**Site Location –** Net loss of sites with archeological or historical significance. **Artifact Location –** Project impact on the location of historic artifacts providing research opportunities.
Social	**Community Cohesion –** Change in physical neighborhood-level connections that unite residents and businesses. **Noise –** Change in noise level in vicinity of project during and after construction. **Visual Quality –** Change in visual characteristics that define community identity. **Emergency Response Time –** Change in time required by fire, police, and medical responders to reach a community. **Citizen's Concerns** – Transportation-related issues of greatest concerns to citizens.
Environmental Justice	**Environmental Justice** – Relative distribution of project benefits and costs across affected population.

Table ES.4. Community Area Measures, by Factor

groups, defined by race, ethnicity, income, or mobility impairment. Therefore, these measures tend to be similar to those found in other factor areas, but are analyzed specifically with respect to these disadvantaged groups to ensure they are not carrying a disproportionate load of the negative impacts of capacity projects.

Table ES.4 summarizes the measures identified in each of the community factors. Additional detail is available in the report.

Cost

Quality cost estimates that remain stable through the planning and programming phases of project development, and that incorporate both direct and indirect costs of a project, are crucial to making informed decisions. Two broad cost factors have been identified for this effort:

- **Cost.** This factor addresses cost estimation management and practice. Issues addressed include the reliability of cost estimates, incorporating unforeseen costs (such as those that result from community concerns), and improving accountability for early cost estimates. Sound cost estimation practices and successful execution of measures in this factor will help reduce the incidence of cost variability.
- **Cost-Effectiveness.** This factor includes traditional aggregate measures of cost-effectiveness such as unit construction cost; productivity or cost indices; analyses of federal/local funding matches and public-private partnerships; as well as more analytical benefit/cost analyses, including techniques for monetization of nontraditional measures.

Table ES.5 summarizes the measures identified in each of the cost factors. Additional detail is available in the report.

Factor	Measures
Cost	**Cost Stability –** Change in cost estimates during the project development process.
	Construction Cost Escalation Factor – Change in price index or key construction material costs.
Cost Effectiveness	**Benefit/Cost (B/C) Analysis –** Monetized project benefits relative to total project costs.
	Project Unit Cost – Total project cost per unit of project delivered.
	Qualitative Cost-Effectiveness – Benefits achieved across measures per dollar of cost.
	Construction Productivity Index – Percentage of total project cost for administrative and change order costs.
	Local/Regional Match – Percent of project costs absorbed by local or regional agencies.
	Private Investment – Private investment in complementary infrastructure.

Table ES.5. Community Area Measures, by Factor

High-Value Opportunities for Data Improvement

In addition to identifying potential measures, the SHRP 2 C02 identified potential data gaps and data gathering opportunities within the environment and community factors. Though each factor has unique data gaps and opportunities, five common themes emerged:

1. **Use of remote sensing for data capture.** Remote sensing technology currently is used to provide data sets that would be prohibitively expensive to collect via field survey methods. Availability of remote sensing imagery provides valuable baseline information for long-range planning and screening of alternatives. Additional work is needed on specific applications of remote sensing for wetland quality, land use classification, and detailed physical features of land cover. Federal or TRB research that provides guidance on use of remote sensing may increase its use to provide data to performance measurement systems, among other applications.
2. **GIS applications for program and project analysis.** GIS-based tools that incorporate multiple data layers and facilitate specific analysis tasks provide tremendous value to planners and project engineers, eliminating the need to identify and track down data sources and develop custom queries and analysis capabilities. Specific applications include integrated screening analysis based on transportation, environmental, land use, and cultural resource data; providing regional overlays of individual agency plans to support cross-agency collaboration; and analysis of transportation facility vulnerability related to climate change.
3. **Modeling and simulation tools.** Development of simulation or scenario analysis tools that build on the GIS capabilities described above would provide further value for early exploration of capacity project alternatives. Potential applications include impact assessment for proposed facilities or programs of projects on water quality, habitat, and historic and cultural resources; and analysis of the implications of various climate change scenarios on infrastructure vulnerability. The Environmental Information Management System and Decision Support System developed as part of NCHRP project 25-23 that presents an opportunity to build a decision support tool.
4. **Interagency partnerships.** Environmental and natural resource agencies at the federal, state, and regional levels offer a wealth of data that are needed to support performance assessments for many of the factors in the SHRP 2 CO2 framework. Transportation agencies already are tapping in to many of these data sources. Partnerships can be pursued at all lev-

els of government to further strengthen data sharing initiatives, leverage existing monitoring resources and jointly pursue development of new data sets and tools that meet common needs. Specific examples of successful partnerships include GIS data sharing agreements in Oregon and New York State, and the North Carolina Ecosystem Enhancement Program.

5. **Data sharing.** A prerequisite to data integration and sharing across disparate data producers and users is availability of metadata that documents dataset content, derivation, accuracy, and suitability for specific purposes. Use of the U.S. federal metadata standards[1] developed by the Federal Geographic Data Committee (FGDC) has become fairly widespread for geospatial datasets. The FGDC also endorses a variety of other standards for specific data types (e.g., wetlands, vegetation, soils.) Programmatic guidelines and tools that encourage and facilitate provision of complete and consistent metadata would be of value.

A thorough examination of data opportunities by factor is provided in the report.

Links to Decision Making

The fundamental purpose of SHRP 2 Capacity research is to improve decision making regarding major capacity projects. This can help improve the environmental and community outcomes of major transportation projects and also speed up the process of project development and potentially reduce costs. Performance measurement can help by providing objective information that can support decision making.

The SHRP 2 C01 Collaborative Decision-Making Framework project has identified several phases of the project development process within which key decisions are made, including long-range planning, programming, corridor studies, environmental review, and permitting. For each of these, the C01 project has identified several key decision points. Table ES.6 identifies potential links between the collaborative decision-making framework and the performance measurement framework.

There are three key concepts in the table that warrant more detailed explanation:

- **Consistency Analysis –** One of the key uses of performance measures for project analysis is as a tool to evaluate how proposed investments by a transportation agency conform to existing plans and studies in other areas. Land use, water, wildlife, and other similar plans help form the context within which transportation agencies make decisions. For some issues, such as air quality, a specific determination of conformity is required, through which expected contributions to criteria pollutants are modeled. Consistency suggests a more qualitative assessment. Examples could include the extent to which proposed investments are in areas that have an established regional transportation-land use vision or a determination if a project is within a vital area for wildlife or water quality, as defined by a habitat or water quality plan.
- **Screening Process –** At several linkages a screening process is suggested. At the long-range planning level, this process is used to qualitatively assess a plan's impact on broad planning factors (e.g., positive or negative impacts on mobility, water quality, etc.). At more detailed levels, the screening process uses measures to evaluate how individual projects or project alternatives will actually impact these factors.
- **Red Flag Analysis –** Agencies can use measures to identify segments of road with known environmental or community concerns. Some agencies maintain a 'red map' of roads to which adding capacity is simply not feasible. Using measures to flag challenging projects early in the process can lead the agency to focus on projects that can be developed easier and faster or to

[1] http://www.fgdc.gov/metadata/geospatial-metadata-standards.

Key Decision Point		Linkage	How Measures Influence Decision Making
Long-Range Planning			
202	Approve Vision and Goals	Select factors	• Vision and goals of the LRP should define the universe of performance factors considered.
203	Approve Evaluation Criteria and Methodology	Select measures	• Measures are selected from within the factors identified in 202; and • General statewide or regional targets should be set collaboratively for measures.
204	Approve Transportation Deficiencies	Use measures	• Use targets set in 203 to determine deficiencies in the state or region; • Environmental PMs used in geospatial analysis of potential 'fatal flaws' for significant natural resources; and • Transportation PMs define level of need (i.e., funding required to achieve targets set in 203).
207	Approve Plan Scenarios	Use measures	• PMs used in a screening process for plan scenarios.
Programming			
301	Approve Evaluation Criteria and Methodology	Select measures	• Measures selected for consistency analysis (i.e., are the set of projects programmed consistent with the vision and goals set in 202); and • Measures selected for prioritization algorithm – readily available data and quantifiable.
302	Approve Project Priority List	Use measures	• Use consistency process or prioritization algorithm to prioritize and select projects.
304	Adopt Conformity by MPO	Use Measures	• Air Quality measures support this process; and • Potential future 'conformity' or consistency processes for GHG emissions or other natural resources.
Corridor Studies			
403	Approve Goals for the Corridor	Select factors	• Goals should be consistent with those developed in 202; and • Goals for the corridor study define the universe of performance factors considered.
404	Approve Evaluation Criteria and Methodology	Provide measures	• Measures are selected from within the factors identified in 403; and • Reasonable range of expectations set for each measure (i.e., what is the best that can be done for congestion or what is the worst allowable impact).
407	Approve Range of Alternatives	Use measures	• Measures used within a high-level screening process to identify feasible alternatives (i.e., those without fatal flaws).
408	Adopt Preferred Alternative	Use measures	• Measures used at a more detailed level to evaluate a narrower range of alternatives in greater depth.
Environmental Review			
503	Approve Purpose and Need	Use measures	• Minor – inform the purpose and needs with performance analysis of the suitability of the proposed solution.
504	Reach Consensus on Study Area	Select measures	• Identify measures that can address the appropriate scale (e.g., corridor, watershed, ecosystem, etc.) relevant for the review.
505	Approve Evaluation Criteria and Methodology	Select measures	• Measures are selected from within the factors identified in 403; and • Specific targets set for measures that require a minimum or maximum regulatory threshold to be met.
507	Approve Alternatives to be Carried Forward	Use measures	• Measures used within a high-level screening process to identify feasible alternatives (i.e., those without fatal flaws).
509	Approve Preferred Alternative	Use measures	• Measures used at a more detailed level to evaluate a narrower range of alternatives in greater depth.

Note: Key Decision Points are taken from SHRP 2 Project C01. Numbers may change.

Table ES.6. Linkages Between Key Decision Points and Performance Measures

identify when extraordinary public and stakeholder involvement may be required to advance a particularly challenging project.

The collaborative decision-making framework is still in development; the links between the key decision points and performance measurement framework will need to be updated as the framework matures. These linkages provide the mechanism for performance measurement to support a collaborative process for selecting and developing major transportation capacity projects.

CHAPTER 1

Introduction and Background

This report documents the work completed for the Strategic Highway Research Program (SHRP 2) Project C02 *A Systems-Based Performance Measurement Framework for Highway Capacity Decision Making.* The goal of SHRP 2 C02 is to create a state-of-the-art performance measures framework that individual transportation agencies and other public agencies can adapt to support the needs of both agencies and stakeholders in the decision-making process for major transportation capacity projects. The framework focuses on providing performance-related data that enable transportation agencies to address the challenges most common in the expansion of highway capacity. It emphasizes performance measurement as a tool to place individual projects within a system context.

Motivation and Objectives

To meet the goal of the project, the research team focused on three key objectives:

1. To develop a framework to implement performance measurement through all stages of project development—from long-range planning through environmental review;
2. To systematically integrate environmental, economic, and community considerations into the analysis of highway expansions; and
3. To support the collaborative decision-making framework being developed by the SHRP 2 C01 team.

Underlying the development of the performance measurement framework is an understanding of several clear motivating factors for the overall SHRP 2 Capacity program effort.

A Comprehensive Evaluation

The SHRP 2 Capacity effort supports a comprehensive evaluation of highway capacity expansion projects from the earliest stages of long-range planning and project development to reduce the frequency and severity of unforeseen issues and constraints.

The performance measurement framework provides a source for a comprehensive evaluation of highway capacity projects by identifying performance measures across a wide range of planning factors (transportation, environmental, economic, community, and cost). These measures allow transportation agencies to review a large number of potential systems (transportation, development, natural environmental, etc.) that may be impacted by a transportation investment.

A Consistent Evaluation Process

The SHRP 2 Capacity effort supports a consistent evaluation of highway capacity expansion projects that can help to speed up the planning and project development process by making sure that work done in the planning stage is useful at later stages of project development.

The performance measurement framework provides an opportunity to improve the consistency of decision making by organizing a set of performance measures used in decision making that are linked to each stage of the planning and project development process.

Intended Users

The primary users of the performance measurement framework are likely to be transportation agencies, especially state departments of transportation (DOTs) and metropolitan planning organizations (MPOs), though large counties and cities also may find useful measures to help with transportation capacity planning.

A secondary set of users includes natural resource agencies and land use permitting agencies (typically municipalities) that play a vital role in shaping transportation infrastructure projects.

The performance measurement framework provides a variety of information that will be useful for different individuals within the organization. Examples of key uses of the framework include:

- As a clearinghouse for information about key factors to address within capacity project development. The framework provides introductory material on a wide range of topics that can help educate all levels of transportation staff who will need to tackle challenges associated with a particular project. For example, transportation practitioners with limited experience in water quality or ecosystem analysis can find key sources for information about these topics.
- As a source of performance measures. The primary purpose of the framework is to help practitioners in multiple disciplines find and define performance measures. The framework helps organize their thinking about measures and provides clear definitions of these measures. Practitioners can easily select and refine measures to suit their individual needs.
- As a means to develop a consistent evaluation process across several phases of project development. Transportation agencies often establish analytic procedures to help identify and prioritize the transportation projects most worthy of construction. In long-range planning and in programming, state DOTs and MPOs examine the overall transportation system and make decisions about which programs and projects should be funded and at what levels. The framework provides information on how measures can be used at the various stages of the process to support these project identification and prioritization methodologies.

Approach and Organization

The SHRP 2 C02 research effort and performance measures framework development evolved through the research process. The research effort began with a broad-based examination of project prioritization processes at transportation agencies, gradually shifting into more targeted analysis of specific issues to be addressed by the performance measures framework.

The first stage of the research effort involved a series of in-depth agency (DOTs and MPOs) interviews to document current practices in capacity project selection and decision making (see chapter 3 for further discussion). Initial findings indicated that many agencies had relevant approaches, but no single agency had developed an entire process that can inform the SHRP 2 C02 effort. As a result, the project team determined that the most effective approach would involve a simultaneous effort of two tasks:

1. Targeted background research with a focus on identifying a broad array of practices, processes, and measures across a large number and types of agencies, rather than an in-depth examination of individual agencies; and
2. Development of a performance measures framework and ongoing testing of that framework against the research findings.

This approach has allowed the project team to further target the outreach to address specific questions as they have arisen in the course of developing the framework, while also helping to inform the evolution of the framework development process throughout.

The remainder of this report describes the development of the framework and the research conducted:

- chapter 2 describes the background research that supported the development of the performance measures framework and its current status.
- chapter 3 introduces the Performance Measurement Framework and describes its several components.
- chapters 4 through 8 present information on each of the five areas of potential performance measurement identified as part of this effort–transportation, environment, community, economics, and cost. These sections provide background literature, performance factors and measures for considerations, and, for several areas, potential data collection to consider.
- chapter 9 summarizes the links between the performance measurement framework and the collaborative decision-making process being developed as part of SHRP 2 Project C01.

Web Tool

The primary product of this research effort is a web tool. This tool includes a database of performance measures organized around the several planning factors identified in five broad areas (Table 1.1).

Within each of these factors, the web tool provides descriptive information about the factor, performance measures to evaluate the factor, and case studies that illustrate the use of many of these measures. Many of the factors included in this framework are interrelated and many measures could be included in more than one area. To make the web tool more useful, measures have been applied to only a single factor.

For each measure, the web tool provides a description of the measure, data that may be required to calculate the measure, the scale at which the measure is typically applied, and potential uses of the measure at various stages of capacity project development (long-range planning, preprogram studies, programming, environmental review, and design and permitting).

The case studies offer examples of recent efforts by agencies to employ measures in the specific factor areas. Many of the case studies are examples of more than one factor area,

Transportation	Environment	Economics	Community	Cost
Mobility Reliability Accessibility Safety	Ecosystems, Habitat, and Biodiversity Water Quality Wetlands Air Quality Climate Change Environmental Health	Economic Impact Economic Development	Land Use Archeological and Cultural Resources Social Environmental Justice	Cost Cost-Effectiveness

Table 1.1. SHRP 2 C02 Performance Factors

and are listed in each factor to which they apply. The case studies include a short description, the factor areas to which the case study applies, the agency responsible for the effort, and a link to more information, if available.

The web tool will be updated as additional SHRP 2 Capacity program projects are completed that address performance measures within individual framework factor areas, such as economics and the environment.

CHAPTER 2

Background Research

The objective of the SHRP 2 C02 effort was to develop a comprehensive performance measurement framework that would support collaborative decision making. To produce the framework, the research team took both a broad look at performance measurement and management and a more focused look at the application of specific performance measures in practice. The supporting research for the SHRP 2 effort was as follows:

- Development of the overall performance measurement framework, based on the broad application of performance management at transportation agencies in the United States;
- A review of the literature on performance measurement, with a focus on 'nontraditional' areas such as the environment, community, and economics;
- Interviews with transportation agencies to determine the extent to which they are using performance measures in various areas identified in the literature; and
- Targeted case studies to identify performance measures and applications at specific transportation and other agencies.

Each of these efforts is described in this section.

Performance Measurement Framework

Many research efforts build a framework or organizational structure deductively, after conducting the research. Because the SHRP 2 C02 project covers such a wide range of efforts undertaken by state DOTs, it was useful to develop a framework up front to help organize the research itself.

This section reports on the efforts to develop the initial framework, which was used as a straw man and modified as appropriate based on research findings.

Framework Development Principles

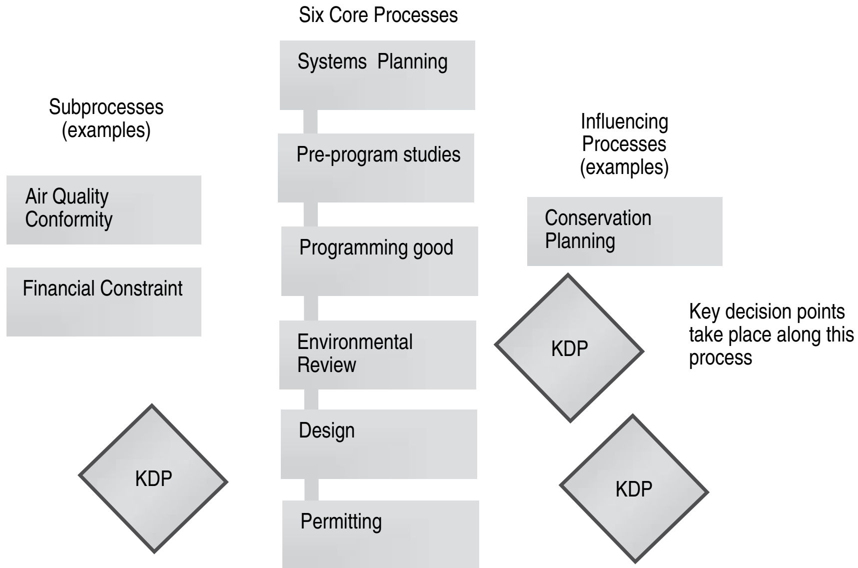
To ensure that the performance measurement framework met the objectives of the SHRP 2 effort, a set of framework development principles was adopted. The criteria used included:

- The framework needs to help identify performance measures for use at several levels – from initial planning and analysis to program development and into environmental assessment.
- The relevant project development stages to which the framework applies should be consistent with those identified by the SHRP 2 C01 collaborative decision-making project (Figure 2.1).
- The framework should help establish the specific issues or factors to be considered at various project development stages. These categories will vary from one transportation agency to another, but the framework should help agencies identify what the appropriate categories are for their consideration.

Existing Performance Measure Frameworks

Numerous state DOTs, as well as other transportation and nontransportation agencies, have developed performance measure frameworks that help shape their programs. As part of the early framework development, several of these existing frameworks were reviewed.

Two examples of existing frameworks were particularly relevant for the SHRP 2 C02 effort. Figure 2.2 presents an example from the Florida Department of Transportation that clearly identifies how performance measures are intended to work through multiple layers and products of an organization. The measures are tied to specific levels of generality (from policy to project) and tied to specific products (long-range plan, short-range plan, projects, etc.). However, the framework does not specify how various issues and concerns are intended to be



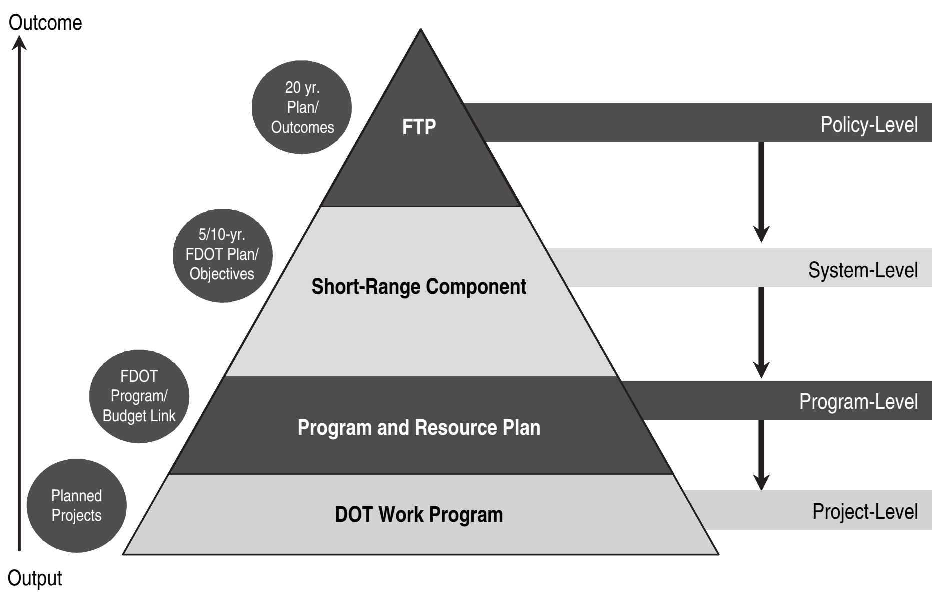
Source: ICF International, Inc., 2007.

Figure 2.1. SHRP 2 C01 core processes.

incorporated in this process, which is a key component of the SHRP 2 C02 research.

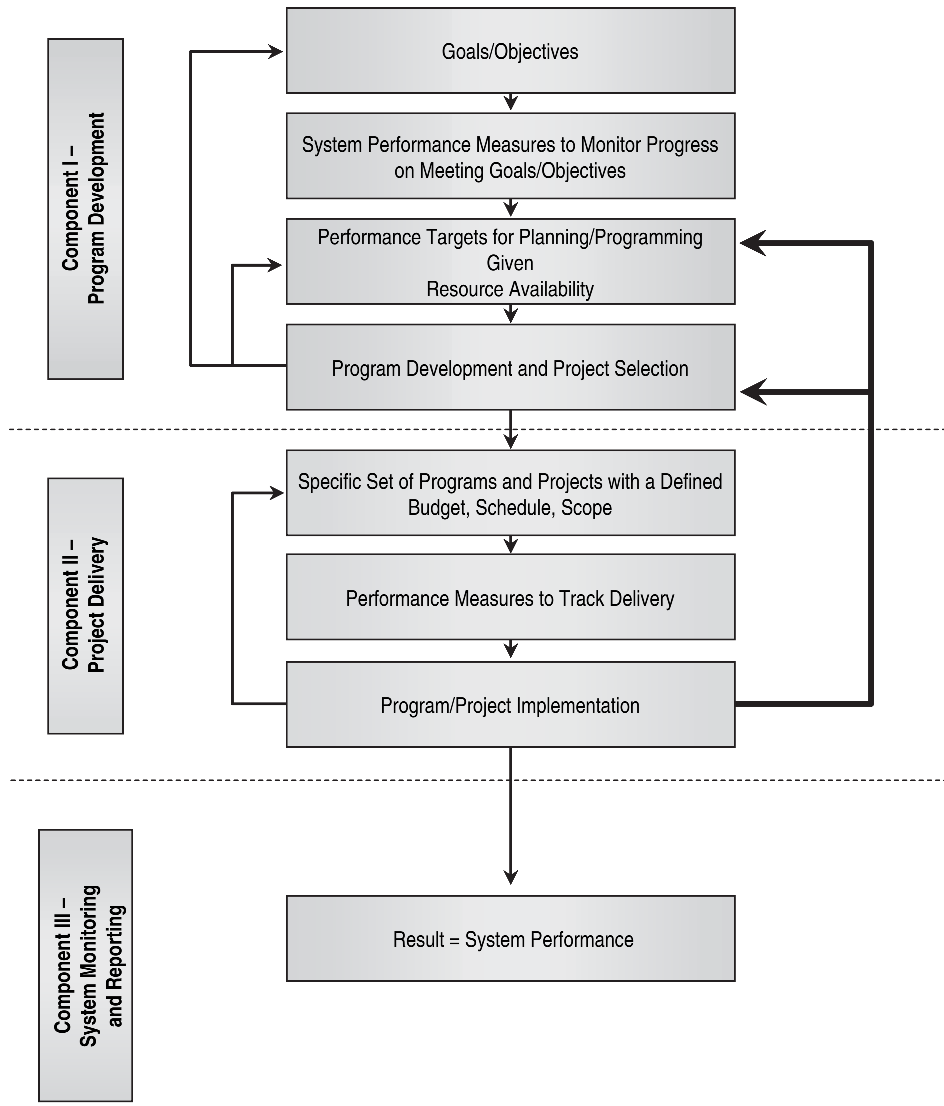
A second example comes from a white paper written for the 2nd TRB Conference on Performance Measurement on developing a performance-based program development and delivery process (Figure 2.3). This approach, commonly referred to as Performance Management, uses performance measures and targets to link agency goals/objectives to specific resource allocations. These allocations usually fall within broad categories such as: 1) system preservation; 2) system management and operations; and 3) system capacity expansion. This latter investment category, capacity expansion, is the focus of the current framework.

One point of this framework is that the issues addressed and measures used at various stages in the process may change as an agency moves from generalized needs to specific projects.



Source: Florida Department of Transportation, 2007.

Figure 2.2. Florida performance measures framework.



Source: Hendren, Neumann, and Pickrell, 2004.

Figure 2.3. Developing performance-based program and project delivery.

The focus also changes from considerations of system performance (mobility, safety, etc.) to organizational performance (project delivery, quality, etc.).

Based on this review and, in following the principles above, an initial draft framework was developed for the SHRP 2 C02 project. This initial framework had two basic dimensions (Table 2.1):

- The stage of project development (across the columns); and
- The factors considered such as mobility, safety, environment, economics, and community (down the rows).

These broad dimensions were adapted and refined as described in chapter 3.

Literature Review

The literature review for this effort focused on materials relevant to development of performance measures to support capacity decision making. It considered measures relevant to the stages of the planning and project development process from long-range planning through environmental review. It primarily considers measures of physical impacts (i.e., amount of congestion, level of environmental harm or benefit), and not measures that address process and project delivery. Five key subject areas were reviewed:

1. General Use of Performance Measures by Transportation Agencies;

Factors	Project Development Phases Relevant to SHRP 2 C02				Phases Potentially Relevant		Phases With Limited Relevance	
	Long-Range Planning	Preprogram Studies	Programming	Environmental Review	Design	Permitting	Construction	Monitoring and Operations
Objective	Identify system needs and projects	Specify projects/ alternatives	Identify mix of projects to be constructed	Select preferred alternative	Specify project completely	Permits from resource agencies	Construct capital projects	Operate the system in real time
Mobility	Measures that identify and prioritize needs	Detailed project analysis	Select projects into program to meet needs	Measures of mobility impacts			Work zone and reliability issues	Evaluate mobility impacts
Safety	Measures that identify and prioritize needs	Detailed project analysis	Select projects into program to meet needs	Detailed measures of safety impacts			Work zone issues	Evaluate safety impacts
Environment	Early issue overview (check boxes)	More detailed overview, but still summary	Criteria – avoid projects with fatal flaws	Detailed environmental impact	Use of environmental best practices	Permit delivery	Environmental monitoring	
Economics	Economic development/ impact measures		Potential selection criteria					
Community	Early overview of issues (check boxes) in regional/corridor studies		Criteria – avoid projects with negative impacts	Detailed measures of community impacts	Use of public involvement best practices			
Other		Reliability			Project delivery (let on time, on budget)		Project delivery (on time/on budget)	Operational measures of reliability

Table 2.1. Initial Performance Measures Framework Issues

2. Performance Measures for Transportation System Enhancement;
3. Performance Measures for Environmental Stewardship;
4. Performance Measures for Community Enhancement; and
5. Performance Measures for Economic Impacts and Development.

The first subject area describes the state of the practice of transportation performance measurement. It reviews the most useful literature and describes the best practices and lessons learned as performance measurement has matured in the transportation industry. The following four subject areas are tied to sections of the performance measurement framework, and are discussed in the relevant section of the report that addresses the specific issue (chapters 4 through 8).

Performance Management

No state DOT conducts highway capacity decision making in a vacuum. The performance measurement framework described in this section for supporting highway capacity decision making is envisioned as part of a broader agencywide performance management system of the kind that some state DOTs are adopting. Performance management is a business process that links agency goals and objectives to resources and results. Figure 2.4 provides two examples of performance measure categories often used in making highway capacity investment decisions – safety and mobility – and shows how performance management is used to link goals and outcomes via use of measures.

With a comprehensive performance management system in place, DOTs use performance measures systematically across a full range of core business functions to support decisions, communicate with external audiences, and manage towards strategic outcomes. A state DOT's strategic mission, vision, goals, and objectives are tied to day-to-day activities via regular review of performance results in core DOT business functions such as pavement and bridge preservation, transportation safety, traffic operations, and infrastructure maintenance.

Performance-based management has three essential and interconnected components: program development, project delivery, and system monitoring and reporting:

1. **Program Development –** Program Development typically begins with establishing agency goals and objectives that are in turn monitored through performance measures. Taking into account resource constraints, performance targets are set and projects and programs are identified and selected based on performance criteria aimed to lead a transportation agency toward its goals/objectives. For example, a state DOT could identify the goal "preserve the existing system" with the related performance measure "percentage of highway miles with acceptable pavement condition." In turn, a project selection (or program budgeting) criterion would be its estimated impact on highway pavement condition. The relationship between performance targets and project selection is an iterative process based on changing needs, available resources, and political support.
2. **Program Delivery –** Program Delivery begins when a set of preselected projects are "passed off" to the delivery team. A performance-based process uses a set of measures to evaluate and monitor project implementation (e.g., percentage of construction contracts completed on time). Figure 2.2 illustrates not only the separation between the selection and delivery of projects and programs, but also

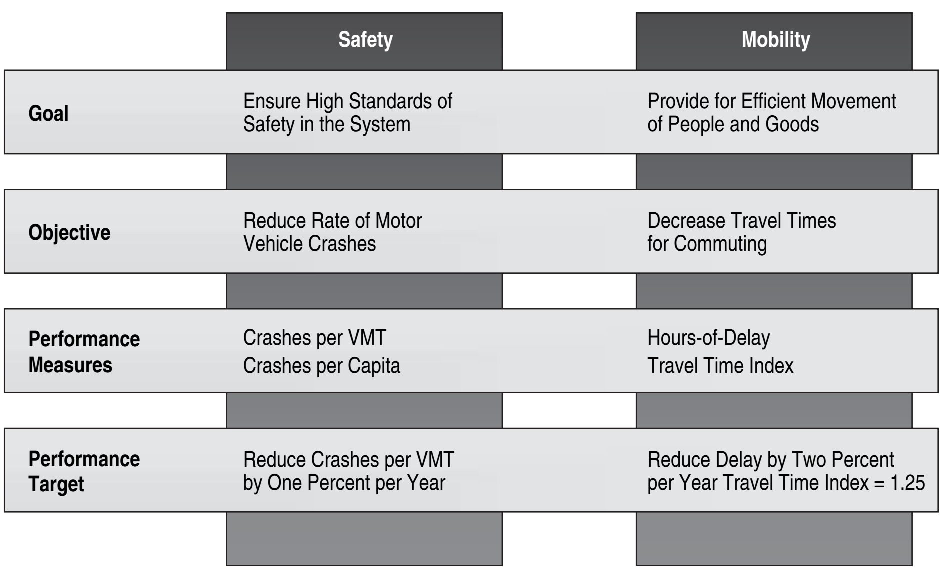


Figure 2.4. Example measures/targets for highway capacity investments.

that there are two distinct groups of performance measures. One set of measures relates to project selection and is linked to agency goals and objectives, while the other set focuses on delivering projects.

3. **System Monitoring and Reporting** – System Monitoring and Reporting measures the changes that occur due to implemented projects and programs. It is the delivery of projects that produces the "result", i.e., system performance. Thus, this component of the process indicates whether the intended goals and objectives of the project have been met (e.g., reduction in travel delays).

The outcomes of performance-based management include more efficient distribution of limited resources and increased accountability and credibility in government.

General Use of Performance Measures by Transportation Agencies

Performance-based decision making has increasingly been used by transportation agencies over the past 10 years in a range of contexts and applications. Defined as a systemic, ongoing process integrated into an agency's planning, management, and decision-making activities *(Pickrell and Neumann, 2001),* it involves a continuous effort of monitoring and feedback that improves decision-making capabilities over time. Though transportation agencies have employed performance measures since the 1950s, the most dramatic evolution of the state of the practice has occurred in the last two decades. Improvements have been driven by:

- Demands from the public and elected officials for increased accountability and performance;
- Emergence of management systems for pavement, bridges, and congestion;
- Strong leadership within the agencies themselves that borrowed from private sector-driven initiatives like "Six Sigma" and "Baldridge Awards"; and
- Recognition that the decision-making environment within which agencies operate has become more complex *(Poister, 2005; Larson, 2005; Bremmer et al., 2005).*

Examining the use of performance measures by transportation agencies is particularly informative. The Government Performance Project (GPP), a nonpartisan, independent research program of the Pew Center on the States, acknowledges many DOTs are leaders in their use of performance measurement and can serve as models for other state agencies *(Government Performance Project, 2005).* Federal transportation agencies are often asked to pilot performance measure processes, and state DOTs are often asked to help other agencies with performance-based initiatives *(Poister, 2005).*

Transportation practitioners in both the private and public sectors have worked diligently to achieve the current degree of performance measurement competency. Numerous peer exchanges and three international invitation-only conferences have been devoted to the subject. The FHWA maintains a web-based *Performance Measurement Exchange,* a thorough and well-maintained list of resources, including discussion boards, citations and links to journal articles, reports and studies, and a directory of practitioners *(Performance Measurement Exchange, 2007).* Furthermore, literature on the use of performance measures by transportation agencies is extensive. It documents the wide range of activities in which measures are relevant and informative. Several efforts comprehensively review the history, development, state of the practice, best practices, and recent trends in performance-based planning *(Cambridge Systematics, Inc., 2000; Hendren et al., 2005; Pickrell and Neumann, 2001; Poister, 1997; Padgett, 2006). Strategic Performance Measures for State Departments of Transportation: A Handbook for CEOs and Executives (TransTech Management Inc., 2003)* describes the core areas in which most DOTs use measures, and the three primary reasons they use measures: communication, management, and decision making. *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management* reviews the literature and addresses several key questions:

- What criteria are used by agencies to select performance measures?
- How are current performance measurement frameworks structured, and what kinds of measures do they include?
- How are performance measures being used to gauge the impacts of transportation investments, support resource allocation and utilization decisions, and assess agency performance in program delivery and cost-effectiveness?
- How are measures being tailored for different levels of transportation organizations?
- How are measures being used to communicate program status – both internally and externally?

NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning provides practitioners an extensive library of measures organized by the following categories:

- Accessibility;
- Mobility;
- Economic development;
- Quality of life;
- Environmental and resource conservation;
- Safety;
- Operation efficiency;
- System preservation; and
- Measures relevant to multiple goal categories *(Cambridge Systematics, Inc., 2000).*

Key Findings

The extensive literature on transportation performance measures points to several general trends.

Performance measures should be driven by strategically aligned goals and objectives. Performance measures should be identified in response to goals and objectives and not the other way around. An agency's goals should reflect the most important aspects of what it wishes to accomplish. Performance measures are the primary means of assessing how successful an agency is in accomplishing its goals. Therefore, it should be clear what goal(s) each measure illustrates advancement of. Failure to properly align measures with goals and objectives can result in tracking measures that have little to do with performance of the organization or transportation system *(Pickrell and Neumann, 2001; Poister et al., 2004; Kittelson & Associates, Inc. et al., 2003).*

Input, output, and outcome measures should all be included in performance measurement. Many of the measures used to monitor systems operations are derived from those developed in the 1950s, and these measures reflect the values of that time, which have evolved significantly. As negative impacts from transportation and other infrastructure investments have become apparent, mainstream concerns have changed to consider a wider range of ways in which transportation affects our communities *(Meyer, 2001).* The type of measures considered for transportation planning has grown to include not only those that consider input (time, capital, resources) and output (speed, throughput, congestion), but also those that consider outcomes to communities and the environment *(Poister, 1997; Poister and Van Slyke, 2001).* Consideration of both output and outcome measures reflect the differences in perspectives of those who manage the system and those who use it *(Shaw, 2003; Kittelson & Associates, Inc. et al., 2003).*

Performance measurement efforts should concentrate on the "vital few." Agencies must use simple, understandable measures and avoid attempting to measure everything *(TransTech Management, Inc., 2006; Larson, 2005; Kassof, 2001).* Providing excessive or redundant measures may overwhelm the end user and obscure key drivers of service quality. As cited in TCRP Report 88, Brown *(1996)* describes this as choosing between "the vital few measures and the trivial many," and suggests an upper limit of 20 measures. Some of the desired "vital few" may not be available during the first iteration of a performance-based process. This deficiency should be addressed in future efforts *(Larson, 2005).*

Early attempts at performance measurement should emphasize process as well as results. Management and staff should set realistic expectations about first iteration results as performance-based planning is an inherently incremental process. The implementation strategy will evolve over time as stakeholder and leadership buy-in improve, performance measures become focused on the "vital few," and technical capabilities advance. Performance-based processes should inform the decision-making process, not replace it, and initial impacts on final decisions may be subtle. Decision makers may initially be slow to accept performance-based recommendations of staff, but they will adopt the additional information into their decision-making process at varying rates as agencywide support for the approach builds. Staff should not give up as providing better quality data from performance measuring efforts can only improve the decision-making process *(Pickrell and Neumann, 2001).*

Performance measurement programs are most effective when integrated throughout an organization. The linkage between program development and project delivery is a vital component to mature, integrated, performance-based methodologies. Few state transportation agencies have implemented both, and fewer have linked the two approaches together. In isolation, a performance-based program development process may identify the best projects to fund but may not guard against excessive scope creep, schedule slippage, or cost escalation. Conversely, a performance-based delivery process in isolation may result in efficient delivery of a program that includes marginal projects. By executing both performance-based program development and project delivery, the most effective set of projects is selected and implemented efficiently *(Hendren et al., 2005; Padgett, 2006).*

Performance measurement reporting should be appropriately tailored to intended audiences. The informational needs of technical staff, decision makers, and the public are different, and presentation and depth of reporting should reflect these needs *(Shaw, 2003; Cambridge Systematics, Inc., 2006; Poister, 2005).* TCRP Report 88, *A Guidebook for Developing a Transit Performance-Measurement System* highlights this diversity, noting the difference in perspective of four different transit stakeholders: the customer, community, agency, and driver. In addition to delivering the right data to the right people, reporting should be as simple and consistent as possible. Aside from providing clarity for decision makers, simplicity and regularity facilitate process improvement of each iteration of the performance-based process *(Larson, 2005).*

Successful performance measurement programs require high-level buy-in. A performance-based approach must have widespread and deep-rooted support to withstand significant changes in leadership. Five key stakeholder groups must accept a program for it to have long-term viability:

- Agency management;
- Agency staff;
- Customers;
- Agency's governing body; and
- Senior contractors *(Kittelson & Associates, Inc. et al., 2003).*

Stakeholders, especially those held accountable for results, should be involved in deciding what to measure, how to measure, and how to convey the results. Most importantly, measures should be used to represent the current state of the system and to focus on opportunities for improvement rather than blame *(Kassof, 2001)*.

Practitioners should strive for consistency of performance measurement terms and definitions. A persistent challenge among performance measurement practitioners is one of terminology. A report in 1999 notes that even discussing performance-based planning first requires a discussion on what exactly the involved parties are talking about *(Cambridge Systematics, Inc., 1999)*. Six years later, two separate reports acknowledge the problem remains persistent *(Bremmer et al., 2005; Poister, 2005)*. *Measuring Performance Among State DOTs (TransTech Management, Inc., 2006)* describes how state departments of transportation may develop and use comparative performance measures to improve communication, promote awareness about best practices and innovations, improve business processes, and increase responsiveness to customers' needs.

In-Depth Interviews

As part of the initial research conducted for the SHRP 2 C02 project, the research team conducted 17 interviews of state DOTs and MPOs to gather information about current use of performance measurement to support capacity decision making. Feedback from these interviews was used as an input into an initial list of performance measures, analysis techniques, and policy considerations to be considered during development of the performance measures framework. The interview focus was on performance measurement for capacity enhancements, but performance measurement processes associated with other project types were reviewed if there was a logical extension to the capacity enhancement approach.

Transportation agencies were selected for profile based on the following criteria:

- **Capacity Expansion –** Is the agency pursuing new capacity or identifying methods to evaluate and prioritize capacity projects?
- **Performance Measures –** What is the agency's history with the use of performance measures of any kind? Have they actively used them to evaluate and prioritize projects, or monitor outcomes?
- **Nontraditional Measures –** Does the agency use nontraditional performance measures or is it developing programs or initiatives to address environmental issues, economic impacts, or community impacts in a unique way?
- **Data –** Does the agency have data management, collection, or sharing programs that are worthy of note?

Agencies interviewed as part of the initial process are identified in Table 2.2. Interviews were completed over the course of three months, May through July 2007, via telephone. Interviews were designed to provide a broad understanding of the use of performance measures in an agency, with additional detail on the specific quantitative methods used, as well as issues and concerns associated with implementing a performance measurement system.

Specific interview questions centered around four main topic areas:

1. **Agency Basics –** Overview of the agency role and authority in managing the transportation system.
2. **Project Identification and Prioritization –** Detail related to the process used to identify, evaluate, and prioritize projects with a focus on the specific criteria and performance measures used to evaluate and select highway capacity projects for funding.
3. **Data and Analysis –** Description of the data and analytic techniques needed to support performance-based decision making.

Agency Type	Agencies Contacted
State DOT	• Arizona Department of Transportation • Florida Department of Transportation • Minnesota Department of Transportation • Montana Department of Transportation • Ohio Department of Transportation • Oregon Department of Transportation • Pennsylvania Department of Transportation • Texas Department of Transportation • Virginia Department of Transportation • Washington Department of Transportation • Wisconsin Department of Transportation
MPO	• Atlanta Regional Commission (Atlanta, Georgia) • Delaware Valley Regional Planning Commission (Philadelphia, Pennsylvania) • East-West Gateway Coordinating Council (St. Louis, Missouri) • Metroplan (Little Rock, Arkansas) • New York Metropolitan Transportation Council (New York, New York) • Sacramento Area Council of Governments (Sacramento, California)

Table 2.2. Transportation Agency Interviews

4. **Political Context –** Additional detail related to the political context impacting funding decisions and "unofficial" constraints on the prioritization of projects.

Although no one interview provided complete information to support development of a performance measures framework, each area provided unique examples of current practice, areas of innovation, and constraints on the decision-making process. Current practice in the area of performance-based decision-making varies greatly by area, depending largely on the level of sophistication in the analysis tools and processes maintained by each state DOT or MPO, as well as data availability and staff/financial constraints. Despite the variability in performance measurement systems, it is clear that there is increasing momentum and support for implementation of performance-based decision-making processes within most state DOTs and MPOs.

Summary of National Trends in Performance-Based Decision Making

The in-depth case studies completed for this phase of the background effort supported the findings of the literature review, discussed in chapter 2. Specifically, performance measurement is becoming much more prevalent, and is being applied in a wide range of contexts throughout the work of both DOTs and MPOs. A number of significant advancements in performance-based processes have occurred over the last decade, largely driven by increasing demands from the public and elected officials for more accountability in the transportation decision-making process, as well as the recognition that the decision-making environment has become much more complex and, therefore, requires more structure and organization.

Transportation agencies have developed both formal and informal performance-based approaches to support transportation investment decisions. The practice at most state DOTs is some variation on a two-stage process. The first stage includes decisions about the amount of funding that will be directed to general program or project types, e.g., maintenance, capacity additions, and operations are typical high-level allocation categories. Decision makers at this level use performance measures to determine the trend in certain key aspects of the system and decide whether more or less funding is needed. In the second stage, decisions are made within project type subcategories, to help prioritize projects with similar need/purpose to aid in programming decisions. The attributes within project type are more nearly similar and quantitative data plays a more important role in developing performance measures to assist in project evaluation and prioritization. For MPOs, project evaluation processes tend to be more focused, e.g., on particular funding categories and within particular geographic areas. This is largely a result of the more stringent fiscal constraint requirements and air quality requirements in air quality nonattainment areas that must be met at the MPO (rather than state) level as part of long-range transportation plan development. Performance criteria by which projects are evaluated are typically well established and vetted, with more refined prioritization processes in place. Evaluation tends to be more specific for projects programmed in the short-term Transportation Improvement Program (TIP), where there is substantially more project information available to support a detailed project review.

For all the state DOTs and MPOs interviewed as part of the interview effort, limited federal and state funding was cited as a key constraint on prioritization efforts for capacity-adding projects. In particular, it was emphasized that the proportion of funding allocated to system preservation and maintenance is increasing significantly, and that the share of funding for capacity improvements is decreasing as a result. Most transportation agencies have a policy in place to preserve and maintain existing systems before constructing new projects. Examples include Ohio DOT's "Fix It First" policy, Minnesota DOT's "Safeguard What Exists" policy, and a preservation first policy in Florida that has been adopted into state law. As emphasized through each interview, more funding is required to preserve aging infrastructure, leaving less money available for programming new (capacity-adding) projects. In many areas, (e.g., Atlanta, Denver), project prioritization is occurring to "deselect" projects that were previously programmed, in order to ensure a fiscally constrained transportation plan and program in the context of limited transportation funding.

In light of severe funding constraints, many areas interviewed have defined a priority transportation network to focus transportation investment, in particular for capacity improvements. Florida, for example, developed the Strategic Intermodal System; the Atlanta Regional Commission and Metroplan in Little Rock, Arkansas, also have identified regional strategic systems within their MPO planning areas to help focus limited funding.

Capacity-adding roadway projects are typically the focus of increased scrutiny due to the greater cost and physical impact of these types of projects. Several agencies interviewed have developed a more refined definition of capacity-addition to demonstrate the capacity benefits of other types of smaller-scale projects. For example, Minnesota DOT and Montana DOT have redefined capacity away from solely mega-projects that typically yield a great benefit for a smaller segment of the system, towards lower-cost projects that provide more incremental capacity across a larger part of the system without major construction and with a smaller physical footprint (e.g., geometric redesign, shoulder improvements). Virginia, by contrast, includes most of smaller capacity improvements in its maintenance budget.

For both state DOTs and MPOs, the critical driver of implementing a performance-based system is using data-driven decision processes to support improved decision making and accountability within the organizations and, ultimately, to improve transportation system performance through better project selection. Only a few state DOTs and MPOs have begun the transition to a full-fledged performance measurement approach toward decision making. However, it seems likely that as budgetary pressures on transportation agencies continue to grow, the use of performance-based decision-making systems will increase.

Common Themes

The interviews uncovered a number of common themes related to implementation of performance measurement systems. Most importantly, and common to all states and MPOs interviewed, the processes are viewed and used as decision-support tools. As such, they do not completely replace qualitative considerations or political realities, and they do not override common sense.

Application of Performance Measures Is Limited by Tools and Data Available

Performance measurement systems and project evaluation/prioritization processes should be quantitatively informed and integrate available data and technical methodologies where available; however, both state DOTs and MPOs report a limited scope for application of data-driven performance measurement systems. In nearly every state, detailed project evaluation tends to be made for capital investments–typically on highways–with congestion reduction and safety impact as the two key performance criteria used in project-level evaluations. This is largely driven by the availability of data and tools needed for detailed analysis, and not a reflection of a lack of comprehensive objectives for transportation investment (e.g., economic development, connectivity, accessibility, etc.) or the lack of support for more expansive project-level assessment (e.g., environmental or community impact). Travel demand models in use by most state DOTs and MPOs do an excellent job of demonstrating the congestion reduction potential of highway capacity-adding projects and generating VMT estimates commonly used in safety analyses, but are limited in their ability to demonstrate additional "off-model" benefits or impacts. Most states and MPOs reported difficulty integrating environmental and community concerns in an objective manner into the project evaluation process.

Increasing Use of Top-Down Approach for Performance Measure Systems

One of the ways that state transportation officials have of targeting budgetary resources is to establish performance measures and/or targets that are adopted by state DOT management, or in some cases, incorporated by the state legislature into law. These measures and/or targets can then be clearly communicated to transportation agencies throughout the state for implementation. In Minnesota, for example, the Mn/DOT's "Safeguard What Exists" policy has three major elements:

1. Preserve essential elements of existing transportation systems;
2. Support land use decisions that preserve mobility and enhance the safety of transportation systems (most measures and targets under this policy are not yet operational); and
3. Effectively manage the operation of existing transportation systems to provide maximum service to customers.

Each policy has a set of measures and targets that allow Mn/DOT officials to monitor progress over time, and that can be used by the district offices in establishing their policy directions and refining project selection.

In many states, including Montana, Florida, and Minnesota, a cross-program analysis is used to determine funding allocations by project type, typically in an attempt to meet predefined targets. Specific project selection responsibility is then devolved to districts, MPOs, or specific program managers within the project types. This typically occurs through a two-step process in which state funding allocations are determined by program/project type within statewide financial constraints through systems-level analysis in the first phase. The funding allocations then serve as the foundation for DOT districts or MPOs to define projects to meet the performance thresholds as part of the second phase. District offices are given a high degree of flexibility in selecting projects, but they are still selected in the context of priorities and funding allocations established through the first phase.

Another interesting example of a top-down approach to establishing performance measurements and targets at an MPO level is found in Atlanta. In March 2005, a Congestion Mitigation Task Force (CMTF) was established by Georgia Governor Sonny Perdue to develop strategies, benchmarks, and goals to cost-effectively reduce congestion in the metropolitan Atlanta area. The CMTF developed three recommendations for incorporation into the regional transportation planning process as shown below:

1. Refine the current transportation project selection process to increase the weighting of the congestion factor to 70 percent;
2. Develop and implement a technically consistent and transparent methodology for benefit/cost analysis; and
3. Use the Travel Time Index to measure improvement in congestion. The Task Force recommended a regional Travel Time Index goal of 1.35 by 2030 for the Atlanta area.

The Atlanta Regional Commission has subsequently developed a refined project evaluation process to accommodate these prescriptive recommendations which was used to develop the latest Regional Transportation Plan.

Increasing Priority to Projects That Are "Deliverable" – Early Environmental Screening

Several states and MPOs interviewed are conducting more robust environmental screening of projects early in the planning process. This supports two larger goals – one, the need to streamline environmental review and reduce the time it takes to implement a project and, two, to help prioritize investment on projects that are deliverable in a reasonable amount of time. Florida has developed the Efficient Transportation Decision-Making Process (ETDM), led by its Central Environmental Management Office, to streamline environmental review and involve resource agencies early on in the planning process. Many other states (Montana, Arizona, Ohio, and Texas) and regions (Atlanta, Denver) also are conducting high-level environmental screening processes as part of plan and program development to "red flag" projects that may take significantly more time to implement due to environmental issues.

Increasing Implementation of Nontraditional Performance Measures

A number of areas interviewed are actively looking to refine project evaluation processes to include nontraditional performance metrics. For example, Florida and Atlanta are both looking to improve travel-time reliability measures, the Oregon DOT has established a Sustainability Program and CS^3 framework (context-sensitive and sustainable solutions) to incorporate sustainability goals into the highway project delivery process, and New York now requires a greenhouse gas inventory to be completed by MPOs as part of transportation plan/program development. Though the trend is to expand the type of metrics included as part of project-level evaluation, transportation agencies are largely limited by data and tools needed to perform meaningful analyses.

Targeted Case Studies

Following the in-depth interviews of state and regional transportation agencies described in the previous section, the research team conducted targeted case studies of programs employing or contributing to a performance-based decision-making process across a wide range of agency types and levels of government.

The purpose of this second phase outreach was to observe performance-based decision making in action, with the goal of filling out and refining the performance measures framework based on real world experience. For each of the factors established by this effort, research team staff:

- Gathered all relevant research or descriptions of performance measure programs;
- Interviewed agencies with experience developing performance measures or data-driven decision making; and
- Synthesized the information gathered from these efforts around four key themes:
  - A **description** of the relevance of individual factors to highway capacity decision making across the stages of the project development process;
  - Detailed lists and descriptions of **performance measures** and how they might be used in the process;
  - Detailed descriptions of **data sources and tools** that are used to support the evaluation of a particular factor; and
  - Summary of **resources** for the factor broadly (e.g., web sites and reports to find out more information about the factor), as well as specific cases of application of performance measures (e.g., case studies).

A total of 54 case studies were developed as part of this effort. A complete list of case studies, including several detailed write-ups is available in Appendix A.

Common Themes, Trends, Successes, and Challenges

This stage of the research process focused on specific programs and not broad initiatives. The objective was to identify measures and processes that could be built into the performance measures framework described in chapters 3 through 8. As such, most of the research generated does not lend itself to broad themes, but is instead more narrowly focused. However, several key themes were identified from this phase of the research.

One of the keys to successful performance-based decision making common to many of the factor areas was the establishment of early warning/clearance mechanisms. Such systems seek to identify "red flags" that might derail or complicate a project before significant resources are invested into planning the project, and before it is programmed. The presence of factors such as significant wetlands, endangered habitats, or archaeological sites can be determined even before formal feasibility studies are conducted, and the discovery of such factors may impact a decision on whether or not to proceed with project planning. Conversely, if a candidate project is found to be unaffected by such factors, its odds of reaching completion without significant unforeseen complications are improved. One of the more innovative examples of this is Minnesota's Mn/Model, a predictive model that uses a variety of available data sources to predict the presence of buried artifacts. The Washington DOT *Transportation Project Mitigation Cost Screening Matrix* is another program specifically designed to provide early clearance or red flagging of the potential mitigation requirements of a proposed project, in the form of a "Mitigation Risk Index" (MRI). Florida's recently implemented Efficient Transportation Decision Making (ETDM) environmental review process also makes significant strides toward identifying and addressing conflicts earlier in the process.

Another encouraging trend found primarily in the environmental area is a shift in emphasis from quantity of resources to quality of resources. This shift has been particularly noticeable in wetlands research, where some of the most advanced practices now focus on the performance of mitigated wetlands, rather than simply the volume. In New Jersey, for example, the Department of Environmental Projection has developed the Wetland Mitigation Rapid Assessment Tool, which seeks to assess whether a mitigated wetland – natural or created – will perform "wetland functions" in the future. Similarly, programs in Pennsylvania and Florida use point systems to evaluate the current status of environmental features throughout the state (Pennsylvania's program focuses on level of wetland degradation, while Florida's measures habitat conservation priority), in order to provide ready information *before* a corridor-specific study is undertaken.

A related theme that has arisen is the potential for technology to improve the tools and data that support decision making. For example, much of the research on environmental quality is in its infancy, but as it develops it has the potential to produce significant evaluation criteria in the transportation sector. This will require a process to translate scientific research into readily used and understood performance metrics.

A common goal of many programs has been to accumulate more advanced, statewide datasets, rather than relying more heavily on project-specific inquiries, and this process has often been combined with more user-friendly reporting methods, often in the form of scoring systems. Such efforts were incorporated into programs studied in Minnesota, Pennsylvania, Washington, and Florida, among others.

Finally, it is clear from the research that the complexity of the issues identified in the SHRP 2 C02 research requires significant translation work to make this information useful to decision makers, especially at early stages of the project development process. During planning and early project development, it is necessary to develop a broad understanding of all of the types of impacts to be considered. Performance measures should help address questions such as: Does a project meet the goals of the transportation agency? Does the project have significant potential environmental or community impacts? These broad questions can be informed by different types of data, but for the information to be useful to decision makers, the basic answers need to be kept simple.

CHAPTER 3

Performance Measurement Framework

For any state, the process of deciding how, where, and when to add highway capacity typically engages many stakeholders in an array of policy, planning, fiscal, public involvement, and engineering activities that are staged over a lengthy time period and involve consideration of many factors ranging from environmental impacts to safety concerns. This section describes the primary dimensions of the performance measurement framework developed for this project.

Collaborative Decision-Making Context – Who, Why, and How

This framework supports a collaborative decision-making process that is under development. The framework is based on performance-based investment decision making or management processes models. Figure 3.1 summarizes the relationship between the collaborative decision-making framework and the performance measures framework.

The Collaborative Decision-Making Framework (CDMF) provides the overall context for the Performance Measurement Framework. The CDMF identifies key decision points in the planning and project development process that could be improved by taking a more collaborative approach. The Performance Measurement Framework helps to support the CDMF by identifying relevant performance factors and measures to consider at the various stages of planning and project development.

Performance measures hold promise as part of the collaborative decision-making tool kit that transportation practitioners can use to make this process more manageable. During the decision-making process, however, hundreds of performance measures may be applicable at different resolutions of detail.

The framework described in this section offers practitioners a way to organize how they use performance measures so they serve as an effective decision-support tool for examining when, where, and how to add highway capacity. The performance measures framework is intended to be flexible, expandable, and modular. It can serve practitioners interested in improving or creating a comprehensive performance measures framework, but it also supports the needs of practitioners looking to capture the impacts on a specific factor, or focusing on a specific phase in the capacity project delivery process.

Creation of a universally applicable performance measurement framework is possible because states' decisions about highway capacity follow the same general pattern and are driven by many of the same basic concerns. Decision making often starts with consideration of broad, statewide needs, solutions, and goals. As consensus emerges, the focus of decision making evolves toward specific consideration of local project-level needs and solutions. Along this continuum, different performance measures can be used at varying resolutions of detail to support decision making.

Creating a framework allows transportation practitioners to customize the specific performance measures they use at each stage of the highway capacity decision-making process to meet unique considerations. For example, sometimes economic impacts may be a primary concern; at others, environmental impacts may the primary issue. The framework helps point practitioners toward the right performance measures to help them make decisions.

The structure of the performance measurement framework is intended to offer flexibility. Capacity-related performance measures may be grouped in two ways; either according to *when* during the capacity project delivery process they are helpful, or according to *what* factors they help to consider during the capacity project delivery process.

The highway capacity decision-making performance measurement framework adopts these two dimensions as organizing principles. In the "capacity project delivery stages" dimension, performance measures are arranged according to their relevance for sequential stages in capacity project delivery from long-range planning, through corridor planning,

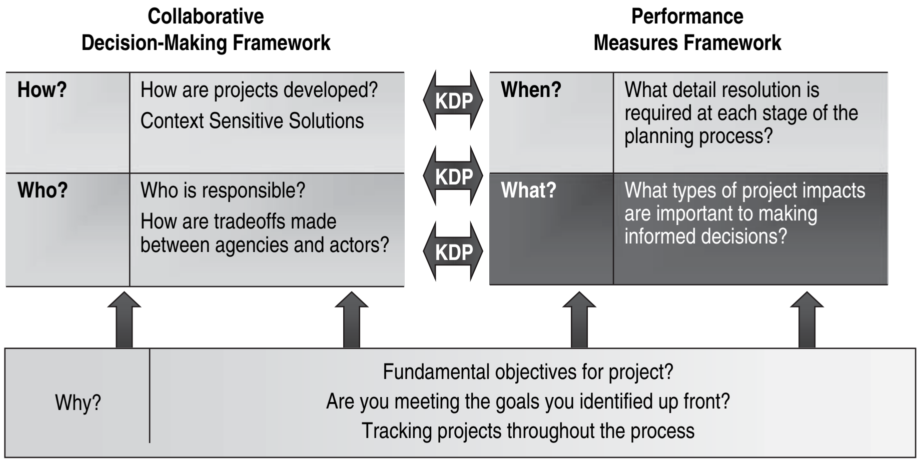


Figure 3.1. Relationship between performance measurement framework and collaborative decision-making framework.

programming, environmental review, to project design. In the "capacity decision-making factors" dimension, performance measures are arranged according to their relevance to critical categories of factors that influence decision making, including transportation, environmental, community, and economic factors.

Linking Measures to Decisions – When

The performance measures identified within each of the factors are intended to support key decisions throughout the phases of the project development process, including long-range planning, programming, corridor studies, environmental review, permitting, and design. This section describes how performance measures can be used in each of these phases.

Long-Range Planning

Performance measures can be used to support capacity-related elements of a state DOT's long-range plan, particularly by bringing leadership accountability to agencywide vision. The long-range plan is customarily a strategic document that defines and builds support for a broad vision that responds to high-priority statewide transportation needs.

As a "map" for policy-makers and their stakeholders, the long-range plan is made more effective by including performance measures that translate an agency's vision into measurable metrics that help DOT leaders gauge and guide statewide progress toward important goals and hold them accountable to stakeholders. The hallmarks of good capacity-related long-range plan-level performance measures include several defining characteristics that together distinguish them from other areas where performance measures are used by DOTs:

- **High-Level Perspective –** Measure(s) offer insights on trends and issues at statewide or regional levels that are relevant to senior DOT leadership, legislators, and the general public;
- **Handful of Measures –** A small, but carefully chosen set of measures helps distill complex data into broad insights that are relevant to policy measures;
- **Reflective of Strategic Goals –** Measure(s) in the long-range plan relate to appropriate strategic goals such as congestion relief, safety, or environmental quality; and
- **Accountable Implementation Focus –** Measures in the long-range plan provide targets from which the success of the long-range plan can be gauged over its life span.

Programming Stage

Performance measures can support state DOTs' capacity-related programming activities. Programming describes the process by which state DOTs select and invest limited transportation funds in a list of projects that will be built in a set timeframe, usually of about three to five years, and that is intended to ensure resources go where they are needed most, including capacity needs. The mix of projects included in a state DOT's program determines how well it is able to address priorities established in the long-range plan or other strategic documents.

Performance measures can improve a DOT's ability to make programming decisions that support achievement of strategic goals. The hallmarks of a good set of programming-level performance measures include several defining characteristics that together distinguish them from other areas where performance measures are used by DOTs:

- **Provide Insights on How to "Close the Gap" –** The program is a DOT's tool to address gaps between current performance and desired targets. Measures should inform decisions on where to apply more resources.

- **Measures are Used as Predictive Tools –** Many of the measures used in conjunction with programming are intended to provide perspective on anticipated future performance as determined by specific investment strategies.
- **Measures Bridge the Gap Between Project and Strategic Levels –** Measures used in programming are based on the expected outcomes of individual projects, but they also can address potential gaps in achieving strategic goals identified in long range planning.

Corridor Studies

Performance measures can support a state DOT's capacity-related preprogram studies. A preprogram study is customarily used by state DOTs and their partners to engage in broad brush thinking about alternative solutions to complex, corridor-level transportation problems. It often includes strategies for addressing capacity needs. As the foundation for subsequent project-level NEPA and design work, a well executed preprogram study expedites delivery of project solutions that meet all stakeholders' needs.

At the preprogram stage, performance measures help planners distinguish between alternative concepts for transportation solutions. The hallmarks of a good set of preprogram study-level performance measures include several defining characteristics that together distinguish them from other areas where performance measures are used by DOTs:

- **Corridor-Level Perspective –** Measure(s) should offer insights on trends and issues at a regional or corridor level that is relevant to DOT managers, local officials, and stakeholders in the project.
- **Applicability to Conceptual-Level Project Solutions –** Measures must be capable of distinguishing among project concepts for which footprint details are vague.
- **Address a Broad Range of Issues –** To help distinguish among project concepts, measures should cover a wide range of metrics – from environmental impacts to economic development potential – that are tailored to specific corridor-level issues.
- **Focus on Supporting Integrated Analysis of Needs and Challenges –** Performance data establishes integrated understanding of both transportation needs and potential impediments to alternative solutions.
- **Data Can be Used to Support NEPA Review –** Performance data and conclusions based on it should be usable in subsequent NEPA studies.

Environmental Review

Performance measures can be used to support state DOTs' capacity-related environmental review activities. Environmental review is the collection of processes that address federal and state requirements for analysis of a program or project's impacts to the natural and social environments. Although the National Environmental Protection Act (NEPA) sets the broad federal guidelines, it is supplemented by a variety of environmental laws, such as the Clean Water Act, Clean Air Act, and Historic Preservation Act; Executive Orders, such as Environmental Justice; and U.S. DOT implementing guidelines, such as Section 4(f) for Parklands and others. In addition, most states now have equivalent legislation that augments federal environmental reporting requirements.

Performance measures can improve a DOT's ability to make NEPA decisions that support speedy project delivery. The hallmarks of a good set of environmental review-level performance measures include several defining characteristics that together distinguish them from other areas where performance measures are used by DOTs:

- **Project-Level Focus –** Measures are used to define the need for the project, to describe the existing environment.
- **Comparison of Alternatives –** Measures gauge potential impacts of multiple alternatives, as well as to determine the significance of those impacts.
- **Bridge Stakeholders Interests –** Measures can be developed to bridge the goals of collaborating resource agencies with the mitigation commitments of the transportation agency.

Design and Permitting

At the design stage, performance measures are not used frequently. Those that are used tend to focus on project and program delivery rather than the direct impacts of individual projects or alternatives. For example, measures can track the delivery status of specific components of a project or the status and function of programmatic permitting efforts.

There are exceptions to this general rule and they usually include measures that can help in the selection of specific design features, including those that help mitigate environmental impacts. For example, the climate change factor includes a measure that addresses the need for infrastructure design to accommodate severe weather events.

Measurement of Capacity Impacts – What

The performance measurement framework is focused primarily on examining the impacts of major capacity investments on five key sets of planning factors: transportation, environment, economic, community, and cost. Table 3.1 presents the specific performance factors identified through this research effort. These factors represent the substantive issues – the what – that performance measures are trying to address.

Transportation	Environment	Economics	Community	Cost
Mobility	Ecosystems, Habitat, and Biodiversity	Economic Impact	Land Use	Cost
Reliability	Water Quality	Economic Development	Archeological and Cultural Resources	Cost-Effectiveness
Accessibility	Wetlands		Social	
Safety	Air Quality		Environmental Justice	
	Climate Change			
	Environmental Health			

Table 3.1. SHRP 2 C02 Performance Factors

SHRP 2 C02 Framework Measures

The specific measures included in the SHRP 2 framework are designed to be general enough so that any agency could adapt them to support their own objectives. In many cases, each of the measures could be calculated and monitored in a number of ways, depending on the tools and data available, and the objective that the measure supports. Chapters 4 through 8 provide detailed examples of applications for each of the SHRP 2 measures.

The performance measurement framework provides hundreds of potential measures. The tenets of performance management described in chapter 2 suggest that performance measures should be selected to reflect a strategic direction for an agency or group of agencies. A strategic direction typically includes a vision or mission statement, a set of high-level goals, and more specific objectives that detail how the agency hopes to achieve progress with each of the goal areas.

From the perspective of this framework, the planning factors represent generic goal statements. In general, it is assumed that a transportation agency pursing a capacity project intends to achieve transportation benefits (i.e., improved mobility or safety), that improve or minimize impacts on the environment (i.e., improve the quantity or quality of wetlands) and the community (i.e., do not disrupt established communities), all while providing the greatest benefit relative to the cost of the project.

The performance measures contained in the framework for highway capacity decision making are linked to more specific, but still generic, objectives. In general, the measures are intended to help address either or both of two broad types of objectives:

1. **Identification and Prioritization of Statewide Capacity Needs –** Some measures can help practitioners identify, understand, and prioritize capacity needs on a regional or statewide scale. A measure such as "throughput efficiency" or "level of service," for example, can be used to identify segments of highway where travel conditions are sufficiently congested to merit consideration of additional capacity.
2. **Support for Evaluation of Project-Level Options –** Once priorities for meeting capacity needs are established, other measures can help practitioners evaluate potential transportation solutions in terms of their impact on a range of transportation, environmental, economic, and community factors. A measure such as "acres of wetlands impacted," for example can help add insight on the relative impact of several possible project-level alignments in a particular corridor.

Based on the literature and case studies conducted as part of this research project, specific objectives were developed within each factor area. Individual agencies will define objectives in more detail to suit the specific conditions they need to address. Examples of agency objectives that reflect this additional level of definition are provided in Table 3.2.

Each objective should be supported by one or more performance measures that can provide information to help an agency make decisions, improve policies and practices, and gauge progress. A set of measures, supporting the established objectives should be selected carefully, with attention paid to the following characteristics:

- **Relevance –** Why is this issue significant to each phase of the capacity decision-making process? What purpose does it serve? How should it be considered differently at the many stages of the transportation planning process? For example, at the planning and preprogram phases, mobility issues are key for identifying transportation needs.
- **Processes and Approaches –** How are or should these issues be incorporated into the specific phase of the process? What agency is primarily responsible for addressing each issue at each phase?
- **Level of Detail –** What type of data and scale are appropriate to support the analysis of this issue? How do the

SHRP 2 C02 – Generic		Example – Specific	
Factor	**Objective**	**Agency**	**Objective**
Mobility	Reduce Recurring Congestion – Improve Travel Time	Arizona DOT – Long-Range Transportation Plan	Maintain and enhance the ability of goods and people to move through and around urban areas with minimal delay.
Air Quality Climate Change *(Environment broadly)*	Reduce greenhouse gas emissions from transportation sources	Florida DOT – Florida Transportation Plan	Make transportation decisions that conserve and optimize nonrenewable resources and promote the use of renewable resources (materials, facilities, and sources of energy) and include strategies to decrease greenhouse gases and air pollutants.
Land Use	Integration of land use and transportation planning efforts	Oregon DOT – Oregon Transportation Plan	Support the sustainable development of land with a mix of uses and a range of densities, land use intensities, and transportation options in order to increase the efficiency of the transportation system. Support travel options that allow individuals to reduce vehicle use.

Table 3.2. Example-Specific Objectives Used to Organize Performance Measures

data and scale requirements change across stages and measures?

- **Quantity versus Quality –** What number of measures and associated data collection and analysis provide the highest return on investment to support effective performance-based decision making?

What is in the Framework

Chapters 4 through 8 describe the SHRP 2 C02 Performance Measurement Framework in more detail. Each section presents the relevant material for each of the five factors identified above. The remainder of this section provides a short introduction to the material that can be found in these sections and in the web tool.

- **Literature Review –** For each of the five broad areas, the relevant literature reviewed as part of this effort is presented. This literature provides the context within which the measures were developed.
- **Performance Factors and Objectives –** Each of the broad areas is separated into a number of factors that capture the range of issues within that area. For example, transportation includes mobility, accessibility, reliability, and safety as the most prominent factors in the consideration of major transportation capacity expansion. Several broad objectives are defined for each factor.
- **SHRP 2 Performance Measures –** Within each factor, a handful of summary level measures are defined. These summary level measures are meant to have the broadest applicability. They are measure concepts that require refinement to be specifically applied.
- **Measure Applications and Case Studies –** For each SHRP 2 measure, one or more specific example measures are defined. Also, each factor includes at least one specific case study that applied one of the measures in the SHRP 2 framework.
- **Data Gaps and Investments –** Detailed information has been compiled on the primary data requirements of each of the performance measures identified as part of the performance measurement framework. In addition, the research team undertook an analysis of potential data gaps and worked to identify high-return investments in data collection, management, and data sharing in the environmental and community areas. Data investments that can be leveraged to address multiple purposes were of particular interest. Detailed treatments of each factor are included in Appendix B.

CHAPTER 4

Transportation Factors

Background Literature

Transportation agencies have been using performance measures to understand the implications of their investments on the transportation system for decades, and these practices stand as a model for incorporating the other factors included in this performance measurement framework. Many performance measures used to plan, operate, and monitor transportation facilities today are descendents of measures conceived in the 1950s *(Meyer, 2001),* including:

- Mobility and reliability measures:
  - Annual average daily traffic per lane-mile;
  - Average travel rate (minutes per mile);
  - Nonrecurring delay;
  - Incident-related delay;
  - Travel time index (median reliability measure);
  - Planning time index (95th percentile reliability measure); and
  - Percentage of vehicle miles of travel under congested conditions.
- Safety measures:
  - Number and rate of fatalities and injuries; and
  - Number of crashes by type, including run-off-the-road, pedestrian, heavy-vehicle, impaired-driver, repeat-offender, uninsured-driver, and unlicensed-driver.
- Infrastructure condition and deficiency measures:
  - Average ride quality;
  - Percentage of asset length or count by condition;
  - Remaining life;
  - Bridge health index; and
  - Bridge deck condition.

These and many other traditional system-related measures are discussed at length in the literature *(Cambridge Systematics, Inc., 2000; Cambridge Systematics, Inc., 2007; Brydia et al., 2007; Shaw, 2003; Cambridge Systematics, Inc., 2005).* Harrison et al., (2006) compile similar performance measurements specifically for freight transportation. The remainder of this section discusses recent trends.

Key Findings

Performance measurement of transportation systems is increasingly operations-oriented. Performance measurement of transportation systems over the last 50 years has been criticized for being reflective of the values held by the engineers expanding capacity of the National Highway System (NHS) *(Hendren and Myers, 2006; Meyers, 2001).* But as the NHS is all but built out, the focus of engineers has shifted from construction to operations. Marginal benefits of operational improvements are typically much smaller than those of capacity improvements, thus new measures are needed to more accurately reflect travel characteristics. Recent literature strongly supports this trend *(Cambridge Systematics, Inc., 2007; Brydia et al., 2007; Randall, forthcoming; Cambridge Systematics, Inc., 2005).*

Performance measures must be viewed from both system and user perspectives. The literature and feedback from practitioners have indicated a trend toward measures that capture how customers experience the transportation system *(Hendren and Meyers, 2006).* Customer-oriented performance measures, including random sample surveys of travelers, web feedback, utilization of traveler information services, press clippings, and media editorials have been used to gauge the quality of the customer experience *(Adams et al., 2005).* Though these outcome measures are important, output measures such as speed, travel time, delays, and number of accidents remain relevant. Perspectives from both the system and the user are needed *(Cambridge Systematics, Inc., 2007; Adams et al., 2005; Shaw, 2003).*

Measures of reliability are growing in importance for both passenger and freight travel. Passengers willingly accept reasonable regular and predictable delays. Users are particularly sensitive, however, to unanticipated delay caused by incidents, construction, weather, demand fluctuations, special events, traffic control devices, or inadequate base capacity. Industry has largely turned to just-in-time production and delivery methods, and similarly it can accept anticipated delays. But variability in travel times can significantly delay shipments beyond expected delivery times *(Harrison et al., 2006)*. Because the highway system is mature, transportation improvements result in increasingly smaller marginal improvements in average travel times. Thus, importance of system reliability is increasing relative to the importance of average travel time *(Cambridge Systematics, Inc., 2000; Cambridge Systematics, Inc., 2007)*.

Measures of mobility and accessibility are distinct but complementary. Mobility represents the ability to travel (e.g., travel time, travel rate); accessibility is the ability to reach desired destinations or activities. Measures of accessibility generally address issues such as:

- Access of persons/households to jobs (e.g., employment opportunities within 30 minutes);
- Access of employers to labor force (e.g., workers within 30 minutes);
- Access of persons to other opportunities (e.g., shopping, school, daycare); and
- Access of persons to alternative modes of transportation, especially transit (e.g., population within one-quarter mile of a transit stop).

There are five categories of accessibility measures:

1. Isochronic (or cumulative) opportunity that measures the number of opportunities (e.g., jobs) within a given travel time;
2. Gravity-based measures that weight opportunities by time/distance;
3. Utility-based measures that weight opportunities by their relative importance/benefit;
4. Constraints-based measures that introduce temporal feasibility; and
5. Composite accessibility measures that combine features of several of the above measures.

Research efforts continue to investigate how to integrate accessibility measures into planning and monitoring efforts *(Chen et al., 2007; Bhat et al., 2006; Levinson and Krizek, 2005)*. A new measure, "Place Rank," is inspired from a methodology used in ranking web pages for the Google search engine. It takes advantage of origin and destination information and can be implemented without knowing point-to-point travel time *(El-Geneidy and Levinson, 2006)*.

Safety performance measurement is advanced in other developed nations. An international scan of performance-based planning found Australia, New Zealand, British Columbia, Canada, and Japan to have particularly advanced safety performance measurement regimes. The team contributed the successes of these countries to their ability to:

- Understand underlying safety problems;
- Establish institutional leadership and accountability;
- Define safety performance measures and targets;
- Collect and analyze data;
- Benchmark results against other agencies; and
- Integrate results into agency decision making *(McDonald et al., 2004)*.

In the United States, performance measurement is a key focus of the Integrated Safety Management System, a system for bolstering highway safety by integrating the disciplines of numerous public agencies *(Bahar et al., 2003)*.

Transportation Performance Factors and Measures

In evaluating major capacity expansion projects, impacts on the movement of people and goods over that system are among the most common considerations. The performance measures framework identifies four categories for evaluating the impact of capacity-adding projects on transportation system performance.

- Mobility;
- Reliability;
- Accessibility; and
- Safety.

Mobility

Mobility refers to the ability of the transportation system to facilitate efficient movement of people and goods. Mobility typically addresses recurring congestion that results when traffic volumes approach or exceed available roadway capacity. Mobility measures do not capture the implications of the location of the congestion compared to desired destinations, but instead simply highlight the extent of congestion in comparison with free-flow conditions.

Two guiding objectives were identified for mobility:

- Reduce recurring congestion – improve travel time; and
- Reduce traffic volume.

Table 4.1 presents seven broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates

SHRP 2 Framework Measure	Specific Measure Applications
Recurring Delay – Difference between the actual time required by motorist to traverse a roadway segment and the unconstrained time.	• Average daily traffic flow per freeway lane; • Ton-miles traveled by congestion level; • Delay per ton-mile traveled; • Lost time due to congestion (per vehicle or experienced by all vehicles); • Vehicle queuing and its relationship to overall delays; • Percentage of time average speed is below threshold value; • VMT by congestion level; and • Percentage of congested miles of state-maintained highways by area (urban, rural), functional class (interstate, priority, etc.).
Trip Travel Time – Time required for a motorist to complete a trip from its origin to its destination.	• VHT per capita; • VHT per employee; and • Average person hours of travel (PHT).
Travel Time Index – Ratio of the actual travel time for a trip compared to the unconstrained travel time.	• Mobility index [person-miles (or ton-miles) of travel/vehicle-miles of travel (PMT/VMT) times average speed].
Volume to Capacity Ratio – Actual number of vehicles using a roadway segment relative to the number of vehicles it is designed to handle over a fixed time period.	• Percent of VMT which occurs at facilities with a V/C ratio greater than 0.71 or 0.8 (or another threshold); and • V/C by route.
Level of Service – Qualitative letter grade of highway operating conditions from A (unconstrained travel) to F (severe congestion).	• Percent of highways not congested during peak hours; and • Number and percent of lane-miles congested.
Vehicle Miles Traveled – Number of vehicles traveling a specified portion of the highway network over a set time multiplied by its length in miles.	• Total VMT; • VMT growth relative to population, employment; • VMT per capita; • VMT per employee; • VMT within urban areas; • Average person miles of travel (PMT); • PMT per capita; • PMT per worker; and • Delay per VMT (by mode)
Mode Share – Number of percent of transportation system users using non-SOV travel means (e.g., transit, bicycle, high-occupancy vehicle travel).	

Case Study Highlight: Mn/DOT 2003 Statewide Transportation Plan

Description: Minnesota's 2003 Statewide Transportation Plan and 2005 district-level plans comprise one of the nation's first comprehensive, performance-based state transportation planning efforts. The Statewide Plan sets a framework for long-range investment planning, with performance measures and targets in 10 policy areas. The district-level plans identify investment levels needed to meet targets and detail a prioritized, fiscally constrained 20-year implementation program. The statewide and district plans serve as the critical link between Mn/DOT's strategic goals and the capital investment program in the Statewide Transportation Improvement Program (STIP). Mn/DOT employs regular performance monitoring to evaluate investment choices and adjust the state's investment program.

Sample Measures:

- Policy: Enhance Mobility in Interregional Transportation Corridors Linking Regional Trade Centers (RTC):
  - Travel Speed – Percent of IRC miles meeting speed targets; and
  - Travel-Time Reliability – Peak period travel time reliability.
- Policy: Enhance Mobility Within Major RTCs:
  - Travel Time – Ratio of peak to off-peak travel time (Travel Rate Index); and
  - Travel-Time Reliability – Peak-period travel time reliability.

Table 4.1. Transportation Measures – Mobility

how the Minnesota DOT incorporated many of these measures into their 2003 Statewide Transportation Plan.

Reliability

Reliability refers to the ability of users of the system to predict the amount of time it takes to make trips on the system. Reliability typically addresses nonrecurring congestion that results from traffic incidents (crashes, breakdowns, special events, weather, and construction). Factors that impact reliability include things such as route redundancy, incident response, and incident rates. Table 4.2 presents four general measures with examples that all support the objective of reducing nonrecurring congestion. The case study highlight illustrates how the Arizona DOT measures incident duration in their MoveAZ Transportation Plan.

Several of these example measures have been adapted from the SHRP 2 project L03 *Analytic Procedures for Determining the Impacts of Reliability Mitigation Strategies.*

Accessibility

Accessibility refers to the ability of the transportation system to connect people to desired destinations through the spatial analysis of residential population, employment centers, and other service or recreation opportunities. Accessibility differs from mobility in that the measures can consider all modes,

SHRP 2 Framework Measure	Specific Measure Applications
Reliability Index – A measure of the additional time (in minutes, percent extra time, etc.) that trips take under congestion conditions relative to uncongested or 'normal' conditions.	• **Buffer Index.** The difference between the 95th percentile travel time and the average (or median) travel time, normalized by the average (or median) travel time (i.e., the percent extra time). • **Travel-Time Index (TTI).** The ratio of travel under congested conditions (i.e., 80th, 95th percentile of traffic flow) to another (i.e., median, mean of traffic flow). • **Planning-Time Index.** 95th percentile travel-time index divided by the free-flow travel-time index. • **Skew Statistic.** The ratio of (90th percentile travel time minus the median) divided by (the median minus the 10th percentile). • **Misery index.** The average of the highest five percent of travel times divided by the free-flow travel time.
On-Time Trip Reliability – Share of trips between a specific origin and destination with travel times below a designated threshold of time.	• Percent of trips with travel times less than 10 or 25 percent higher than the median travel time; • Percent of trips with space mean speed less than 50, 45, or 30 mph; and • **Throughput Efficiency** – Difference between actual average speed of vehicles traversing a roadway segment and speed at which maximum throughput occurs.
Incident Duration – Average time elapsed from notification of an incident to incident clearance.	• Average time elapsed from notification of an incident until all vehicles have moved to shoulder; • Average time elapsed from notification of an incident until all vehicles have been removed from scene; and • Average time elapsed from notification of an incident until all last responder has left the scene.
Crash Analysis – Identification of high crash locations by roadway segment.	• Location of highest crash rate (accidents per traffic volume); and • Number of locations with crash rate higher than national average (accidents per traffic volume).

Case Study Highlight: Arizona DOT MoveAZ Transportation Plan

Description: MoveAZ is the Arizona DOT's current long-range transportation plan. MoveAZ was developed using a comprehensive performance-based planning effort to support a process in which needs and projects identified in the plan ultimately move to programming and development based on clearly defined metrics and project performance. A list of 20 performance measures was developed to assist in project selection and plan development.

Sample Measure:

- Reduction in hours of incident-related delay – the total incident delay for a given district in 2002. If a project reduces incident delay below the 2002 level, it only receives that portion of the improvement to the 2002 level.

Table 4.2. Transportation Measures – Reliability

and focus specifically on the congestion on those roadways that inhibit key travel for a particular population or trip type. Typical accessibility objectives include:

- Provide residents access to regional centers;
- Provide businesses access to market resources; and
- Improve or maintain transportation equity.

Table 4.3 lists five general measures that support these objectives, including examples of each measure. The case study highlight illustrates how Albany, New York's congestion management process measures destination accessibility.

Safety

Safety refers to the ability for users of the system to reach their destination safely on any given trip. This is typically measured through the record of crashes or incidents along a particular roadway or at a specific intersection. Although transportation projects often focus exclusively on safety, the focus in this framework is on the safety impacts of highway capacity expansion projects. The following two measures (Table 4.4) support the objective of improving safety. The case study highlight demonstrates how the Denver Regional Council of Governments measures crash rates in their 2008-2013 Transportation Improvement Program.

SHRP 2 Framework Measure	Specific Measure Applications
Job Accessibility – Number of jobs within a reasonable travel time for a region's population.	• Percent of population within 30 miles of employment; and • Percent of population within 45 minutes of employment.
Destination Accessibility – Average travel time to major regional destinations.	• Average travel time from facility to destinations; • Origin-destination travel times; • Accessibility index; • Percent of population within five miles or 10 minutes of state-aided public roads; • Average number of job opportunities close (within 20 or 40 minutes, by peak automobile and peak and off-peak transit); • Average number of home-based shopping opportunities (trips attracted by stores; based on 10-minute automobile and 20-minute transit travel times); • Average number of home-based other opportunities (within 20 minutes by automobile and 40 minutes by transit); • Percent of population close to a college and close to a hospital (within 20 minutes by automobile and 40 minutes by transit); • Percent of population close to a retail destination (within 10 minutes by automobile and 20 minutes by transit); • Average travel time for work trips; • Average travel time for home-based shopping trips, home-based other trips; • Average travel time to the CBD; • Percentage of population group with transit access to the CBD; • Average number of jobs accessible within 15, 30, and 45 minutes by transit and automobile; • Average number of low-income jobs accessible within 30 minutes by transit; and • Average number of schools, food stores, health services, social services accessible within 30 minutes by transit and automobile.
Labor Force Accessibility – Number of residents within reach of the region's employers.	• Change in average travel time to major employment centers as result of project; • Change in number of employees within 45 minutes travel time to major employment centers as result of project; and • Percent of employers that cite difficulty in accessing desired labor supply due to transportation.

Table 4.3. Transportation Measures – Accessibility

SHRP 2 Framework Measure	Specific Measure Applications
Market Accessibility – Average travel time to market centers.	• Change in population within 45 minutes travel time to important market centers as result of project; • Percent of wholesale and retail sales in the significant economic centers served by unrestricted (10-ton) market artery routes; and • Percent of manufacturing industries within 30 miles of interstate or four-lane highway.
Environmental Justice Accessibility Impact – Relative jobs, destinations, labor force, and market accessibility for environmental populations versus the general population.	• Level of access for disadvantaged populations to jobs, services, and market centers.

Case Study Highlight: Albany, NY Congestion Management Process

Description: Albany's Capital District Transportation Committee uses their Congestion Management Process (CMP) to identify the regions' congestion management needs as part of the region's RTP. The CMP reports current values of performance measures and anticipated future values under alternative growth scenarios. These performance measures are related to transportation service (access, accessibility, congestion, flexibility), resource requirements (safety, energy, economic cost), and external effects (air quality, land use, environmental, economic).

Sample Measure:

- Travel Time between Representative Locations by Quickest Mode:
  - Sample Time: State Office Campus to Northway Exit 10 (minutes, P.M. Peak).

Table 4.3. (Continued).

SHRP 2 Framework Measure	Specific Measure Applications
Safety – Crashes per hundred million vehicle-miles traveled.	• Accident risk index ('safety index'); • Accidents (or injuries of fatalities)/PMT; • Fatality (or injury) rate of accidents; • Hazard index (calculated based on accidents per VMT by severity); and • Number of accidents per ton-mile traveled.
Crashes – Absolute number of crashes over time (e.g., per year).	• Accident rate, deaths, injury, property loss by type of corridor; • Average duration of accidents; • Number of pedestrian accidents (or injuries or fatalities); and • National rank for accident, injury, fatality rates.

Case Study Highlight: Denver Regional Council of Governments FY 08-13 TIP

Description: DRCOG's project evaluation process for its latest Transportation Improvement Program (FY 2008-2013) includes a unique scoring system for each type of project, including roadway capacity. The scoring system is categorized into 10 topics: current congestion, safety, cost-effectiveness, condition of major structures, long range plan score, transportation system management, multimodal connectivity, matching funds, project-related Metro Vision implementation and strategic corridor focus, and sponsor-related Metro Vision implementation. Each category has a unique scoring system, and receives up to 15 points depending upon how that category is weighted. Project sponsors submit their project online, complete this ranking process, and are given an instant score. This gives them a sense of how their project will compare to others, and what areas they need to improve in order to increase the chances for funding.

Sample Measure – Based on the project's estimated crash reduction and weighted crash rate in comparison to the statewide average, up to 5 points will be awarded:

- Using the estimated number of crashes reported by the applicant for the three-year period, the funding request application program will convert that to a per-mile basis and will assign the crash reduction level as follows:
  - Low (9 or fewer crashes eliminated per mile);
  - Medium (10-19);
  - High (20-29); and
  - Very High (30 or more).

Table 4.4. Transportation Measures – Safety

CHAPTER 5

Environmental Factors

Background Literature

Prior to the 1970s, the environmental effects of transportation projects were investigated but not heavily weighted in decision making. Many of these negative impacts went unmitigated due to a lack of universal governing policy or community awareness and understanding regarding the gravity of these harmful environmental effects. The 1969 National Environmental Policy Act (NEPA) advanced the state of the practice by requiring environmental review of all federal actions, including transportation improvements. As these reviews began to uncover "fatal flaws," major environmental issues that threatened environment health and costly delays to projects that had been under consideration for years, transportation agencies began considering environmental issues earlier in the planning process *(Amekudzi and Meyer, 2005; Evink, 2002)*. But the practice of environmental performance measurement is not yet comprehensively developed or practiced within state DOTs. Many admit they are not as advanced in this field as they wish to be *(Cambridge Systematics, Inc., forthcoming)*.

Though environmental performance measurement is not yet fully developed, several reports address environmental issues within the context of transportation planning and implementation *(Amekudzi and Meyer, 2005; Evink, 2002; Venner, 2005; Venner, 2004; The Louis Berger Group, Inc., 2002)*. *NCHRP Report 541: Consideration of Environmental Factors in Transportation Systems Planning* comprehensively assesses state- and metropolitan-level practices for addressing the environment in transportation planning. Based on these findings, it presents an approach for integrating environmental factors in transportation planning and decision making *(Amekudzi and Meyer, 2005)*. The FHWA maintains the Environmental Guidebook, a portal to 47 environmental topics of concern to transportation practitioners *(FHWA, 2007)*. Through a partnership with FHWA, the American Association of State Highway and Transportation Officials (AASHTO) operates the Center for Environmental Excellence. The Center's objective is to promote environmental stewardship and encourage innovative ways to streamline the transportation delivery process. It maintains a comprehensive web site to serve these purposes *(AASHTO Center for Environmental Excellence, 2007)*.

The literature reflects a convergence of trends toward both environmental stewardship and performance-based planning *(Cambridge Systematics, Inc., forthcoming; Venner, 2003; TERM 2001, 2007)*. Several related resources are organized under the rubric of sustainability (*Sustainable Development Strategy, 2007-2009, 2006; CST, 2002; Litman, 2006)*. Transportation agencies such as the Washington State Department of Transportation (WSDOT) and Transit New Zealand are leading efforts both in the United States and abroad to incorporate environmental performance measures into their decision-making processes *(Measures, Markers, and Mileposts, 2007; Environmental Plan, 2007*).

Current examples of common environmental measures have focused on either air quality measures, which are well established or environmental inputs and outputs, which can be more easily measured than outcomes. Some examples include:

- Tons of pollution (or vehicle emissions) generated;
- Total area of wetlands impacted/mitigated; and
- Number of water quality-related watershed restoration projects.

The remainder of this section identifies attempts to better incorporate environmental concerns into transportation decision making including using performance measures. Recommended environmental outcome measures for the SHRP 2 effort follow.

Key Findings

Departments of transportation are working with partners to better address environmental issues throughout the

transportation planning and project development process. One effort that takes a comprehensive approach to the environmental impacts of transportation projects is *Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects,* developed cooperatively by a team of eight federal agencies and four state DOTs. *Eco-Logical* defines an ecosystem approach based on: 1) integrated planning (i.e., agencies working together and with the public to determine transportation and environmental priority areas); 2) exploring mitigation options that include potentially mitigating off-site and with nonimpacted resources; and 3) using performance measures to track progress. "Green infrastructure" provides another framework for understanding the natural environment as integral to the infrastructure we rely on. Green infrastructure refers to the interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches, and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for America's communities and people. Just as communities need to upgrade and expand their gray infrastructure (e.g., roads, sewers, utility lines), so too they need plans to upgrade and expand their green infrastructure. Green infrastructure plans provide a blueprint for conservation in the same way that long-range transportation plans provide a blueprint for future roads or transit lines. These plans can create a framework for future growth while also ensuring that significant natural resources will be preserved for future generations.

State agencies already utilize many methods of integrating environmental concerns into transportation decision making. California DOT's (Caltrans) Division of Environmental Analysis manages its Standard Environmental Reference, an on-line resource compiled to assist state and local staff in planning, preparing, and submitting environmental documents. Arizona, Florida, and New York have information systems to track projects and associated major milestones. Florida Department of Transportation's (FDOT) system, part of the Efficient Transportation Decision Making (ETDM) process, allows staff from multiple collaborating agencies to input and update information about transportation projects. FDOT began tracking 23 performance measures to gauge the efficacy of the ETDM process in 2005. Vermont DOT (VTrans) and WSDOT compiled an Environmental Operations Manual to guide environmental procedures on transportation projects *(State DOT Environmental Programs: Evaluation and Performance Measures, 2007).* FHWA, EPA, the Maryland State Highway Administration, the National Asphalt Pavement Association, the American Concrete Pavement Association, and several other organizations have established a Green Highways Partnership with the objective of minimizing the impacts of transportation projects on the environment *(Green Highways).* The emphasis of the program is on the implementation of best management practices, especially with respect to watershed-driven storm water management, recycling and reuse, and conservation and ecosystem management *(Paving the Way . . . , 2006).* Green Highways is a voluntary, nonregulatory collaboration of private and public partners at both the state and federal levels to identify opportunities that will improve the environmental impacts of transportation systems. Opportunities include joint funding, technology transfer, collaboration, and joint research. Leaders are recognized and rewarded for their good practices, thereby encouraging others to adopt similar practices.

Efforts to develop environmental performance measures must continue to overcome practical challenges. Many environmental issues are difficult to quantify and may be outside the scope of influence of transportation agencies. Certain data are sometimes difficult and costly to obtain. Instead of working with resource agencies, transportation agencies often collect primary data themselves *(Cambridge Systematics, Inc., forthcoming; Venner, 2003).* Determining the appropriate temporal and geographical scales to monitor is particularly challenging because ecosystems contain a wide variety of interdependent flora and fauna, each having its own lifespan and range of habitat *(Evink, 2002).*

Transportation agencies need to engage environmental resource agencies in a variety of ways. Transportation agencies must work with resource agencies for a variety of reasons. State transportation agencies commonly fund positions within overworked resource agencies to expedite reviews of transportation projects. Most DOTs report that these arrangements are helping to avoid problems, allow early consultation and development of programmatic approaches, and troubleshoot problems when they arise (*DOT-Funded Positions . . . , 2005; Venner, 2003).* Transportation agencies also create Memorandums of Understanding and share information with resource agencies such as the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration Fisheries Service, the National Park Service, and the U.S. Department of Agriculture *(Eco-Logical, 2006).* However, transportation and resource agencies alike note the time-consuming nature of developing interagency partnerships and how this hinders widespread application of streamlining techniques *(Venner, 2005).* A Gallup *(2004)* survey of transportation and resource agencies involved in interagency environmental efforts noted differences in perceptions of how well the efforts were working among participating organizations. A survey of 10 pilot projects indicated that collaboration is hard work, time-consuming, labor-intensive, and expensive *(Bracaglia, 2005).*

New tools for transportation decision making incorporate environmental considerations and facilitate environmental performance measurement. Numerous tools already incorporate environmental performance measures into transportation planning, design, construction, maintenance, and operations *(Schwartz, 2006; Amekudzi and Meyer, 2005)*. Environmental Management Systems (EMS) and related Environmental Information Management Systems (EIMS) are used to support the NEPA process, track commitments, and manage public involvement *(Cambridge Systematics, Inc., forthcoming; Cambridge Systematics, Inc. et al., 2006)*. Remote sensing equipment and Geographic Information Systems (GIS) facilitate data collection, analysis, and reporting *(Muller et al., 2007; Thieman, 2007; Donaldson and Weber, 2006)*. On-line statewide GIS repositories are making a variety of previously unavailable datasets known to transportation planners, including air quality, endangered species, wetlands, and water quality data *(VIGN, 2007; WiscLINC, 2007)*.

Environmental Performance Factors and Measures

Environmental impacts of highway capacity projects have traditionally been addressed through the National Environmental Policy Act (NEPA) process, parallel state processes, and related federal and state regulations. These efforts focus on minimizing the impacts of new or expanded infrastructure through modifications to specific alignments and mitigation of those impacts that cannot be avoided. These efforts have typically focused narrowly on the transportation right-of-way, but recent federal and state efforts are shifting how environmental factors are addressed by: 1) considering the relationship between transportation and the natural environment more broadly, with a focus on protecting and enhancing quality environmental areas, rather than mitigating the impacts of specific projects; and 2) understanding and addressing environmental factors starting at the earliest stages of project development, especially long-range planning. Six performance factors have been identified within the environmental element of the framework, including:

- Ecosystems, Habitat, and Biodiversity;
- Water Quality;
- Wetlands;
- Air Quality;
- Environmental Health; and
- Climate Change.

Each of these factors is discussed below in more detail, including specific performance measures and applications of those measures. In addition, though not directly applicable to the framework, performance measures were identified in the areas of energy, materials, and waste. These are discussed at the end of this section.

Ecosystems, Habitat, and Biodiversity

Highways can cause direct loss of habitat resulting from road construction; fragmentation and isolation of existing habitats; obstacles that limit migration and dispersal and create smaller, more inbred populations; and animal-vehicle collisions resulting in wildlife mortality and a serious safety concern for the traveling public. Recent work in this area focuses on the way an entire ecosystem works, rather than narrowly examining impacts on individual species. In general, three broad objectives are considered in this area:

- Maintain or improve ecological functions of potentially affected ecosystems or habitat areas;
- Minimize harm to wildlife species; and
- Protect native plant communities.

Table 5.1 presents four broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates how Arizona's Wildlife Linkage Program measures loss of habitats.

Water Quality

Considering the effects of highway capacity on water resources can help protect water resources and also ecosystems, biodiversity, wildlife habitat, and endangered or sensitive species that rely on healthy aquatic ecosystems. Water quality protection has historically been considered after project sites have been selected, but there is growing support for considering water quality protection much earlier in the planning process, before environmental and permitting processes are required. Recent work in this area focuses on a watershed approach that considers the functions of individual water bodies in an overall system.

- Maintain and improve water quality; and
- Minimize indirect impacts on water quality at watershed scale.

Table 5.2 presents eight broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates how Colorado's I-70 Mountain Corridor Tier 1 EIS captures the impact of highway capacity projects on water quality.

SHRP 2 Framework Measure	Specific Measure Applications
Loss of Habitats – Impact of transportation construction on degradation in quality and quantity of land essential to the survival of target plant or animal species.	• Acres of fragmented or threatened habitat in the state or region; • Change in number of acres of a specific habitat; • Change in composition and structure of habitat; • Change in the amount of habitat edge (locations where habitat stops or starts); • Change in the acreage of interior habitat; • Distance of habitat fragments from each other; • Preservation of high-quality wildlife habitat (wetlands, old-growth forests, etc.); • Number of projects that protect sensitive species or restores habitat; • Number of acres of priority conservation areas acres protected annually; • Sustained population ecology (increased size and density of species, balanced age and sex structure, reduced mortality, new growth, etc.); and • Population size of indicator species.
Natural Resource Plan Consistency – Consistency between natural resource plans and transportation project plans.	• Project contributes to the goals and objectives identified in the natural resource plan. • Project sponsor has coordinated with local natural resource agency to align project with goals and objectives. • Project has expected impacts on high-priority sensitive natural resources as identified in a natural resource plan. • Is ecosystem protection incorporated into the agency/authority's strategic planning as an articulated goal or objective? • Have existing ecosystem protection and related efforts (e.g., habitat conservations plans) been identified and screened for relevancy? • Number of state highway miles with up-to-date natural resource maps relative to total that need mapping.
Animal-Vehicle Collisions – Impact of transportation projects on the number and characteristics of collisions between animals and vehicles.	• Number of vehicle collisions with animals listed on the endangered species list; and • Change in animal-vehicle collisions.
Losses of Native Plants – Impact of transportation construction on the quality and quantity of native plant communities.	• **Losses of Native Plants –** Impact of transportation construction on the quality and quantity of native plant communities: – Change in health and diversity of native plant community; – Change in acres of native plants relative to nonnative plants; – Change in acres of invasive plants within highway corridor right-of-way; – Percent of native vegetation preserved; – Number of acres with newly planted native plants; – Acres sprayed with herbicide; – Total square feet of noxious weed infestation, per 0.10-mile section; and – Total square feet of nuisance vegetation, per 0.10-mile section.

Case Study Highlight: Arizona's Wildlife Linkage Assessment

Description: The purpose of this effort is to identify critical habitat connectivity areas and potential linkage zones that are important to Arizona's wildlife and natural ecosystems. Nine public agencies and nonprofit organizations collaborated to produce an assessment document and map which provide a first step toward identifying large blocks of protected habitat, potential wildlife movement corridors through and between them, the factors that could possibly disrupt these linkage zones, and opportunities for conservation. The non-binding document and map serves as an informational resource to planners and engineers, providing suggestions for the incorporation of these linkage zones into their management planning to address wildlife connectivity at an early stage of the process.

Sample Measure: Each transportation project is evaluated in the context of the Wildlife Linkage Assessment, and what the probable impact will be. The Assessment provides a common reference point for all projects under consideration.

Table 5.1. Environmental Measures – Ecosystems, Biodiversity, and Habitat Factor

SHRP 2 Framework Measure	Specific Measure Applications
Water Quality Protection Areas – Impact of transportation construction on priority water quality protection area.	• Degree of intrusion of transportation infrastructure into water quality protection area; • Proximity of transportation projects to receiving waters; • Proximity of transportation projects to water bodies with established TMDLs; • Change in pollutant loadings for nutrients; • Expected pollutant emissions from construction and operation of new transportation infrastructure; and • Percent of water samples collected that meet state quality standards for clarity when working in water.
Hydromodification – Impact of transportation construction on water quality due to the alteration of water bodies by transportation projects.	• Extent of modification of a water body as a result of new capacity investment (significant, minor, none); • Change in sediment load (predicted or observed); • Change in nutrient load (predicted or observed); • Change in temperature (predicted or observed); • Change in velocity on receiving water body (predicted or observed); • Degree of steam bank and shoreline erosion (predicted or observed); and • Number of culverts retrofitted for fish passage, number of barriers removed at major construction projects.
Losses of Riparian and Floodplain Areas – Impact of transportation construction on the quality, quantity, location, and functioning of the areas adjacent to the affected water bodies that strongly influence water quality.	• Change in acres of riparian areas; • Acres of riparian areas disturbed or degraded; • Acres of riparian areas improved; • Change in ecological function of riparian areas impacted by a capacity investment; • Amount of watershed improvement achieved after five or more years through appropriate measures; and • Acres of open space land protected from development.
Water Resource Plan Consistency – Consistency between water resources and watershed management plans and transportation project plans.	• Project contributes to the goals and objectives identified in the watershed management plan; • Project sponsor has coordinated with local water resource agency to align project with goals and objectives; and • Project has expected impacts on high-priority sensitive water resources as identified in a water resource plan.
Construction-Related Water Quality Impacts – Impacts on water quality due to highway construction.	• Change in turbidity due to construction activities; • Change in sediment loads due to construction activities; • Change in pollutant loads due to construction activities; • Quantity of dredged material disposed at various sites (ocean, coastal waters) and used for various purposes (wetlands creation); and • Percent of surface waters degraded from highway development projects.
Water Quality Standards Compliance – Consistency of transportation project-related water quality impacts with water quality standards.	• Project impact on TMDLs and water quality standards for specific water bodies; • Available pollutant loads prior to exceeding allowable thresholds; and • Average pollutant concentrations of various metals, suspended solids, and toxic organics in road runoff.

Table 5.2. Environmental Measures – Water Quality Factor

SHRP 2 Framework Measure	Specific Measure Applications
Highway Runoff – Change in water quality due to added highway capacity.	• Change in pollutant loads due to change in highway capacity based on VMT; • Change in pollutant loads due to change in highway capacity based on new lane-miles; • Proximity of new road to receiving waters; • Percentage of urea (deicing compound) discharged directly to surface waters; • Pollutant loads during "first flush" events; • Quantity of oil and grease loading via road runoff; • River miles, lakes, and ocean shore miles impaired by urban runoff (not just highways); • Amount of road salts generated per VMT or per lane-mile; and • Per capita vehicle fluid losses.
Impervious Surface – Impact on watershed water quality due to additional buildings, roads, and other impervious surfaces built as a result of added transportation capacity.	• Increase in impervious surfaces due to direct facility construction; and • Increase in impervious surfaces due to development induced by facility construction.

Case Study Highlight: Colorado I-70 Mountain Corridor Tier 1 EIS

Description: The Colorado DOT (CDOT) has undertaken a Programmatic EIS to identify solutions for the I-70 Mountain Corridor between Denver and Glenwood Springs. The PEIS examined the indirect impacts of alternatives, including land use and development patterns, and the resulting impact on various environmental indicators. Environmental areas addressed include wildlife movement and habitat, threatened and endangered species, vegetation, wetlands, riparian areas, fishery resources, streams, winter maintenance, stormwater runoff, land use, growth effects, economic effects, visual resources, recreation resources, historic properties, air quality, noise, geologic hazards, regulated material and mining waste, environmental justice, and public lands (4(f) properties).

Sample Measures: For each alternative the following issues were considered:

- Water quality issues from winter maintenance activities and impact of stormwater runoff – Measured in sediment, suspended solids, phosphorus, sodium chloride;
- Identified water quality impaired streams and TMDLs – Measured in sediment;
- Identified water supply sources (including drinking and public water supplies – Measured in sediment, phosphorous, chloride;
- Issues associated with stream stability hydraulic function, and stream health – Measured in instream flow requirements, ammonia, sediment, temperature, dissolved oxygen;
- Issues associated with spills or release of hazardous materials associated with transport on I-70 – Measured in various possible types of spills; and
- Identified antidegradation standards, nonpoint, and point sources – Measured in nutrients, ammonia, phosphorus, suspended sediment, instream flows, dissolved metals, chloride, dissolved oxygen, temperature.

Table 5.2. (Continued).

Wetlands

Wetlands are complex ecosystems that, depending on their type and on circumstances within a watershed, can improve water quality, provide natural flood control, diminish droughts, recharge groundwater aquifers, and stabilize shorelines. They are vital to both water quality and ecosystem function. Regulated by the Clean Water Act, wetlands can be addressed by the watershed and ecosystem approaches identified under the water quality and ecosystems factors. There has been a recent move toward the consideration of wetlands quality, and not solely quantity, in project planning and programming processes.

- Minimize taking of wetlands; and
- Enhance ecological integrity by minimizing impacts to high-quality wetlands.

Table 5.3 presents three broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates how the Washington State DOT's Transportation Project Mitigation

SHRP 2 Framework Measure	Specific Measure Applications
Ratio of Wetland Acres Taken and Replaced – Annual impact of transportation construction on statewide amount of wetlands lost compared to new wetlands built.	• Annual acreage of wetlands destroyed versus wetlands created.
Losses of High-Quality Wetlands – Impact of transportation construction on high-value wetlands.	• Change in acreage of high-quality wetlands; • Expected change in ecological function of wetlands as a result of mitigation for capacity investments; and • Ecological value of wetlands impacted by a capacity investment.
Wetlands Plan Consistency – Consistency between wetlands plans and transportation project plans.	• Project contributes to the goals and objectives identified in the wetlands plan; • Project sponsor has coordinated with local wetlands (or natural resource) agency to align project with goals and objectives; and • Project has expected impacts on high-quality wetlands as identified in a wetlands plan.

Case Study Highlight: Washington DOT Transportation Project Mitigation Cost Screening Matrix

Description: The Transportation Project Mitigation Cost Screening Matrix or "screening tool" is a tool that helps transportation planners identify proposed projects that may benefit from the application of watershed-based mitigation. The screening tool analyzes readily-available data on urbanization, floodplain areas, soil types, topography, wetlands, hazardous materials, parks, and other cultural resources. Projects that encounter these features commonly have the highest environmental mitigation costs, especially for stormwater treatment and wetlands replacement. The tool generates a "mitigation risk index" or "MRI" consisting of a single score that estimates the percentage of land area within the project limits that will likely experience logistical difficulties or elevated costs for in right-of-way environmental mitigation. Specific to wetlands mitigation, the tool includes a "Potential Wetland Restoration Site Environmental Benefits Ranking Criteria."

Sample Measures:

- Site has extensive hydrologic alteration – Loss of hydrology can mean the total conversion of the site from wetland to upland. Sites with extensive hydrologic alteration have the greatest potential to restore many of the recognized wetland functions.
- Site has extensive vegetation alteration – Sites with extensive forest clearing have potential to restore some flood storage/flow control, water quality, temperature maintenance, and organic export functions.
- More than 50 percent of site has Hydric Code A or B soils – Site has increased potential for providing groundwater recharge function.

Site has surface hydrology connection to river/stream – improve site's ability to provide impacted functions and priorities from City Comprehensive Plans. One point if site has surface water connection, 2 points for regular surface water flooding, and 1 additional point if the site's stream reach supports fish species.

Table 5.3. Environmental Measures – Wetlands Factor

Cost Screening Matrix is used to measure the losses of high-quality wetlands.

Air Quality

Clean Air and transportation legislation has required the integration of the transportation and air quality planning processes since 1970. This integration is intended to ensure that transportation decisions are consistent with the air quality goals for a region. Current requirements include the transportation conformity process, which requires that projects within transportation improvement programs do not exceed air quality standards for an area.

- Meet National Ambient Air Quality Standards; and
- Reduce carbon monoxide and particulate matter hotspot violations.

Table 5.4 presents two broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates how carbon monoxide and particulate matter concentrations are measured in the Minnesota DOT's 2003 Statewide Transportation Plan.

Climate Change

Climate change should be addressed both in terms of transportation impacts on the climate, and the potential impacts of climate change on transportation infrastructure. A conformity process, similar to what is used for other emissions, may suggest a method to address transportation's impacts on climate change. Research suggests that climate change will significantly impact transportation infrastructure through rising sea levels and related changes.

SHRP 2 Framework Measure	Specific Measure Applications
Transportation Conformity – Comparison of actual on-road transportation-related emissions in air quality non-attainment or maintenance region versus desired level of emissions identified in state's air quality plan to ensure national ambient air quality standards are met or exceeded.	• Change in air quality conformity status due to increased emissions; • Number of urban areas (or population in areas) classified as nonattainment status; and • Expected impact of new capacity investments on criteria pollutants.
Carbon Monoxide and Particulate Matter Concentrations – Contribution of projects to localized CO or PM violations in nonattainment and maintenance areas.	• **Carbon Monoxide and Particulate Matter Concentrations –** Contribution of projects to localized CO or PM violations in non-attainment and maintenance areas.

Case Study Highlight: Mn/DOT 2003 Statewide Transportation Plan

Description: Minnesota's 2003 Statewide Transportation Plan and 2005 district-level plans comprise one of the nation's first comprehensive, performance-based state transportation planning efforts. The Statewide Plan sets a framework for long-range investment planning, with performance measures and targets in 10 policy areas. The district-level plans identify investment levels needed to meet targets and detail a prioritized, fiscally constrained 20-year implementation program. The statewide and district plans serve as the critical link between Mn/DOT's strategic goals and the capital investment program in the Statewide Transportation Improvement Program (STIP). Mn/DOT employs regular performance monitoring to evaluate investment choices and adjust the state's investment program. Environmental measures are used to monitor impacts on air quality, water quality, land management, and streamlining of the environmental process. These measures are calculated on a statewide scale to support the goal of "protect(ing) the environment and respect(ing) community values."

Sample Measures:

- Federal Compliance Standards: Outdoor levels of ozone, nitrogen oxide, carbon monoxide and particulate matter;
- Estimated carbon dioxide emissions from motor vehicle in Minnesota; and
- Percent of Mn/DOT fuel consumption defined as cleaner fuels.

Table 5.4. Environmental Measures – Air Quality Factor

- Reduce greenhouse gas emissions from transportation sources;
- Reduce risk of damage to transportation infrastructure or disruption of transportation service due to global climate change; and
- Offset greenhouse gas emissions from transportation sources.

Table 5.5 presents three broad performance measures to address these objectives and specific applications of each performance measure. The case study highlight illustrates how the Puget Sound Regional Council measures greenhouse gas emissions in their Vision 2040 plan.

Environmental Health

Although the topic of environmental health is broad, this framework focuses on the issue of mobile source air toxics, a by-product of vehicle emissions and a well-documented contributor of cancer and noncancer human health problems. This is an emerging area of research.

- Minimize near-roadway human health risk from air toxics.

Table 5.6 presents two broad performance measures to address this objective and specific applications of each performance measure. The case study highlight illustrates how air toxics exposure was measured in the Sacramento/I-5 Aerosol Transect Study.

Energy, Materials, and Waste

The SHRP 2 C02 framework is primarily focused on the evaluation of major highway capacity projects in planning, project development, and environmental review. The considerations of energy, materials, and waste are generally addressed during design, construction, and operation of the transportation system, and thus fall outside of the primary focus on this effort. However, several general measures have been identified in these areas, as they are important complements to the other set of issues addressed in this factor area. Table 5.7 provides a set of measures consideration.

Environmental Data Gaps and Opportunities

The evaluation of environmental impacts is one of the top priorities of the SHRP 2 C02 Performance Measurement Framework. A set of potential data investments was evaluated for this area. Findings by planning factor are summarized here. Additional detail on these data investments can be found in Appendix B.

SHRP 2 Framework Measure	Specific Measure Applications
Greenhouse Gas Emissions – Total amount of transportation-related pollutants that cause global climate change.	• Expected change in greenhouse gas emissions as a result of capacity investments (e.g., using EPA's Motor Vehicle Emissions Stimulator).
Infrastructure Vulnerability – Susceptibility of transportation infrastructure to damage caused by environmental hazards associated with global climate change.	• Level of vulnerability (e.g., extremely vulnerable, vulnerable, not vulnerable) to sea level rises expected as a result of climate change; • Level of vulnerability (e.g., extremely vulnerable, vulnerable, not vulnerable) to storm frequencies and severity expected as a result of climate change; and • Level of vulnerability (e.g., extremely vulnerable, vulnerable, not vulnerable) to temperature changes expected as a result of climate change.
Carbon Sequestration – Net change in quantity of carbon stored in biomass located along transportation corridors as a result of construction and operations-related vegetation management practices.	• Sequestration capacity of existing vegetation; and • Sequestration capacity of planned vegetation.

Case Study Highlight: Puget Sound Regional Council (PSRC) Vision 2040

Description: PSRC's long-range transportation plan, Destination 2030, and regional transportation/land use plan, Vision 2040, were developed using an extensive array of performance measures addressing mobility, safety, land use, the environment, and other issues. The agency has implemented performance monitoring systems to continue to track transportation and land use trends in the region. Projects included in the region's TIP must be included in, or consistent with, Destination 2030.

Sample Measure:

- Outcome – Air pollutants and greenhouse gas emissions are reduced;
- Measure – Annual average emissions of greenhouse gases; and
- Data Source – Puget Sound Clean Air Agency.

Table 5.5. Environmental Measures – Climate Change Factor

SHRP 2 Framework Measure	Specific Measure Applications
Air Toxics Concentrations – Impact of transportation construction on concentrations of mobile source air toxics.	• Expected concentrations of mobile source air toxics as a result of capacity investments.
Air Toxics Exposure – Proximity of vulnerable populations potentially affected by mobile source air toxics.	• Number of housing units, schools, hospitals, and nursing homes within 240 meters of existing or new right-of-way; • Number of housing units, schools, hospitals, and nursing homes within 240 meters of a transportation facility right-of-way with significant truck volumes (i.e., over 10,000 trucks per day); • Number of nursing homes within 240 meters of ROW; and • Number of days that Pollution Standard Index is in an unhealthful range.

Case Study Highlight: Sacramento/I-5 Aerosol Transect Study Winter Months 2003-2005

Description: The American Lung Association of Sacramento – Emigrant Trails Task Force conducted this study to continue monitoring the air quality impacts of I-5, compare the data to other sites in California, and conduct a thorough study of aerosols on a particular community. During the period December 12, 2002 through January 16, 2003, fine aerosol mass, (fine liquid or solid particles suspended in the air) was collected continuously and measured every three hours along a nine site transect from west of Davis, California, to Shingle Springs, California. The fine $PM_{2.5}$ aerosols were size segregated into either three or six size modes above 0.09 μm diameter. Coarser aerosols were also measured at five of the sites. The direct impact of I-5 and a secondary roadway monitored on downwind sites was evident in all weather conditions. On many days, aerosol mass values were similar across the entire network, but with an enhancement at the sites downwind of I-5.

Sample Measure:

- Levels of fine aerosol mass measured and compared at specific sites (museum, middle school site) and across entire network to understand impact on populations.

Table 5.6. Environmental Measures – Environmental Health Factor

Potential Framework Area	Potential Measures
Energy Consumption	• Final energy consumption in transport by mode and energy sources; and • Share of final energy consumption in transport produced from renewable energy sources.
Materials	• Amount of solid raw materials used in building transport infrastructure; and • Amount of solid raw materials used in vehicle manufacture.
Waste	• Total amount of nonrecycled waste generated by transport mode and by type of waste; • Number of motor vehicles scrapped annually; • Estimated annual garbage generation by transportation sector; • Amount of wastewater produced in transport manufacturing industries or service infrastructures not treated in wastewater treatment plants; and • Number of tons of recycled/waste materials used in construction projects.

Note: Energy, materials, and waste were not specifically included as factors within the SHRP 2 C02 performance measurement framework but are included here as additional measures that may be broadly useful in evaluating transportation infrastructure.

Table 5.7. Environmental Measures – Energy, Materials, and Waste

Water Quality

Analysis of the impacts of highway projects on water quality requires bringing together land, hydrology, and biological data, as well as information derived from planning efforts to identify sensitive areas and/or areas to be targeted for improvement. Assessments may include proximity of the proposed highway project to receiving waters within identified water protection areas, encroachment on riparian or other sensitive areas, projected increases in pollutant load due to the project (related to runoff, displacement, or hydromodification), impacts on compliance with established water quality standards, consistency with existing water resource plans, or impacts on impervious surfaces (considering the highway itself as well as associated induced development).

A wealth of information exists for water quality analysis, including searchable national GIS data sets and query tools. Key gaps for performance assessment are the lack of tailored data sets and tools for assessing impacts of highway capacity projects on watershed health and impervious surfaces. Data and tools also are needed for enhanced analysis of stormwater management, beyond the existing focus on total maximum daily load (TMDL) assessment.

The greatest opportunities for progress in addressing data gaps in the water quality area are through partnerships between transportation and other agencies with an interest in environmental protection and natural resources. Such partnerships could focus on data sharing via clearinghouses that provide access to multiple GIS data layers needed for project screening or more detailed impact analysis. Partnerships also may extend beyond data sharing and include ongoing collaboration at the planning and programmatic level. (The North Carolina Ecosystem Enhancement Program is one example of this). This model provides a more holistic context for analysis and joint planning of transportation improvement programs and watershed quality improvements.

There also may be opportunities at the federal level for collaboration between U.S. DOT, EPA, USGS, and other agencies to develop methodologies and tools for more sophisticated simulation capabilities for water quality (and other environmental) impacts.

Ecosystems, Biodiversity, and Habitat

Highway project impacts in this area are typically considered at the project level as part of the NEPA permitting process, though a few states have implemented broader approaches that go beyond looking at individual transportation projects and are integrated with planning efforts of environmental and natural resource agencies. DOTs typically collect data on road kill; other data used for analysis within this area (landscape and ecosystem data, species data) come primarily from agencies outside of the DOT. Key data sources include EPA, Fish & Wildlife, USGS, and NOAA at the national level; Wildlife Action Plans and Natural Heritage Programs at the state level; and Ecoregional Conservation Assessments provided by the Nature Conservancy. Significant quantities of data related to ecosystems, biodiversity, and habitat are collected by dozens of governmental, academic, and private organizations.

The major gap in this area is the current fragmentation of data sources, making it difficult to locate and integrate information when needed. Key opportunities for improvement include GIS data sharing agreements and web-based GIS data access, and interagency collaboration allowing for integrated planning approaches. One specific approach to collaboration involves development of a regional ecosystem framework for assessment of cumulative impacts of multiple infrastructure and development projects.

Wetlands

State DOTs typically track wetlands loss due to transportation project construction, as well as wetlands replacement acreage in compensatory mitigation related to projects. While these measures provide a gauge of the quantity of impacts to wetlands, they do not provide an understanding of true ecological consequences at a broader, watershed level. This would require better information on the location, types, and quality of wetlands lost and on the long-term success of mitigation sites. Availability of this kind of data is uneven and fragmented across multiple agencies. Consideration of statewide wetland quality data early in project development would enable DOTs to select project alignments that minimize mitigation costs and strengthen environmental stewardship.

There are two opportunities for improving data on wetland quality:

1. Development of improved remote-sensing-based data collection methods. These methods provide a cost-effective estimation of wetland quality which currently is gathered through time-intensive field surveys. Several states are experimenting with these methods.
2. Further development of model monitoring programs for statewide tracking of the effectiveness of wetland mitigation sites. Programs in North Carolina and Washington State provide a useful starting point.

Environmental Health

Within the performance measurement framework, environmental health focuses on mobile source air toxics (MSAT) that may contribute to human health problems. Information of interest includes ambient concentrations of MSATs, potential impacts of new highway projects on MSAT emissions, and proximity of vulnerable populations to major roadways. The science on air toxics is still evolving and data are limited. Key gaps are availability of data on ambient concentrations in proximity to highway corridors of interest, understanding of how future vehicle fuel mix changes will impact prevalence of different MSATs, and data that provides an ability to translate measured or modeled MSAT concentrations to health risk factors.

Three opportunities for improvement in this area were identified:

1. Development of partnerships between highway agencies and EPA, state, and local environmental agencies to monitor MSAT concentrations in key areas of concern presents a cost-effective way to leverage existing data and monitoring resources;
2. Investment in a meta-analysis of existing site-specific MSAT studies could help to identify best practice mitigation measures that may reduce the need for near-road air toxics monitoring; and
3. Provision of support for ongoing efforts outside of the DOT community to advance the state of knowledge about MSAT exposure and health effects.

Climate Change

Climate change measures are only beginning to be introduced as part of state DOT and MPO decision making. There are two distinct areas of concern:

1. Impacts of highway projects on greenhouse gas (GHG) emissions; and
2. Potential impacts of climate change effects on future vulnerability of highway facilities.

Rough measures of GHG emissions can be derived from fuel consumption statistics at a system level, and from estimated VMT and fuel economy at the project level. Improved accuracy would require incorporating information on average speeds, drive cycles, and vehicle types–which would require more complex assumption and/or use of more advanced modeling and simulation techniques. The shift toward nonpetroleum fuels is increasing the level of uncertainty in emissions estimation; additional data are needed to improve understanding of the GHG emissions of these fuels. Development of life-cycle models for GHG emissions would improve accuracy and confidence levels in estimation of GHG emissions from transportation projects.

Measures of climate change-related risk to transportation facilities require integration of multiple factors: location, condition, and criticality of infrastructure; probability of impact; and the degree of severity of multiple climate change factors, including changes in temperature, precipitation, sea level rise, storm surge, coastal and inland erosion, ice and snow melt, and permafrost condition. Risk assessment must be tailored to specific regional and localized conditions. Though several global circulation models are available to project climate change at national and regional scales, the current state of science involves levels of uncertainty that preclude specific projections at more localized scales. Another gap is the lack of standardized data on locations and elevations of infrastructure, in geospatial format. This information is essential for assessment of risk for facilities in coastal areas and other sensitive locations.

Development of a geospatially based platform that integrates transportation and climate information would facilitate climate-change-related risk assessment and would be an effective way to leverage available data. Such a platform should incorporate data on facility location, emergency evacuation routes, land and facility elevations, locations of protective structures; and trends in precipitation levels, temperatures, storm surge heights, relative sea level rise, and location and duration of flooding events. It should enable scenario-based analyses involving differing assumptions about precipitation levels, temperatures, relative sea level rise, severe storm frequency and intensity, storm surge heights, and areas of inundation. This effort would require interdisciplinary partnerships between transportation and environmental agencies.

CHAPTER 6

Economic Factors

Background Literature

Transportation investments have the potential to affect net economic growth and spatial and temporal distributions of wealth. They influence the economy not only by affecting user costs such as energy consumption, vehicle maintenance, accident frequency, and travel time, but also business costs associated with inventory, logistics, reliability, just-in-time processing, and fluctuations in market areas for workers, customers, and deliveries. But financial resources are always limited, thus it is important for decision makers to consider economic costs and benefits of potential projects and programs and select those that maximize the positive outcomes to the greatest extent possible *(Lakshmanan and Chatterjee, 2005; Weisbrod et al., 2001; Lewis, 1991)*.

There are two types of costs and benefits: those that accrue to users of the system, and those that accrue to the economy at large. Methods for identifying user costs include life-cycle cost analysis and benefit/cost analysis (BCA). Methods for determining cascading impacts throughout the wider economy, known as economic impact analysis (EIA), vary with complexity. Simple methods for EIA include surveys, market studies, and comparable case studies. More complex methods include econometric productivity models and input/output models. The most advanced economic impact assessment models integrate with travel demand models, land use models, and dynamic simulation economic models. Several reports review the importance of economic analysis and present technical methods, best practices, and pitfalls to avoid. *(FHWA, 2003; Lewis, 1991; AASHTO, 1977; Weisbrod and Weisbrod, 1997)*. The Economic Development 2002 Conference (TED2002) was devoted to these and other topics related to transportation economics, including rural travel, freight movement, decision-making techniques, and joint development efforts *(Roskin, 2003)*.

The methods used to determine economic impacts result in performance measures that aid decision makers in project or program selection. Thus the results of these methods, which rely on performance measures of other types (e.g., mobility through monetized travel-time savings, safety through crash reductions and associated costs) may themselves be considered economic performance measures:

- Life-cycle cost;
- Life-cycle benefit;
- Net present value;
- Rate of return;
- Benefit/cost ratio;
- First-year benefit ratio; and
- Payback period *(FHWA, 2003; Lewis, 1991; AASHTO, 1977)*.

A separate set of performance measures is relevant to economic *development* impacts. For example, studies worldwide have shown greater access to larger employment markets increases the potential for people to earn higher incomes, thus improving metropolitan economic performance. Measures of accessibility to jobs have been suggested as proxy indicators for economic growth *(Cox, 2007)*. Other common measures of regional economic development include:

- Jobs created;
- Gross regional product (GRP); and
- Change in personal income.

Regional economic development benefits can be incorporated into the economic impact measures described above (i.e., on the benefits side of the equation) although caution must be used to ensure that benefits are not double-counted with other benefits such as mobility/travel-time savings.

Key Findings

The remainder of this section examines important trends with respect to economic impacts of transportation investments.

Economic trends indicate increasing demand for transportation. Globalization and international trade are increasing the amount of goods moved across borders. Freight is moving over longer distances as companies decentralize and outsource their manufacturing processes. Just-in-time production technology and an increase in small, lightweight, high-value goods are increasing the importance of travel time and reliability. Intermodal goods movement is increasing, not only as a result of international trade, but also as businesses seek the most efficient combinations of modes. Business and leisure air travel is increasing as long-distance business relationships increase and as wealth and personal incomes rise *(Cambridge Systematics, Inc., 2002b).*

Agencies should attempt to consider the full range of costs and benefits in their analyses. Monetization of performance measures relating to mobility, safety, system preservation, environmental quality/health, and economic development holds promise, though measures relating to customer satisfaction, environmental justice, quality of life, security, and sustainability are more difficult to monetize *(Economic Development Research Group, Inc., 2007).* In addition, some state transportation agencies may be resistive to economic analyses for several reasons:

- Skepticism concerning accuracy of the available technical methods due to perceived uncertainties in valuing costs and benefits;
- Perception that the workload is excessive relative to agency resources; and
- Concern the results could conflict with preferred or mandated outcomes.

These concerns are largely unwarranted as known uncertainties may be managed, BCA becomes easier with practice (especially for less complex projects), and objective and independent assessment of economic consequences can only contribute valuable information to a decision process *(FHWA, 2003).*

Benefit/cost analysis and economic impact analysis are two distinct methods. BCA, and the related net present value (NPV), demonstrate whether a project is worth the resources that will be invested in it. Economic impact analysis (EIA) demonstrates how these benefits and costs will be distributed throughout the economy. The results of these studies are complementary, not additive *(FHWA, 2003).* Two recent statewide studies demonstrate the difference. Colorado DOT adapted benefit/cost analysis methodologies from several agencies and organizations to estimate user benefits and costs for three alternative investment scenarios based on its 2030 long-range transportation plan. The study did not quantitatively consider wider impacts on the economy *(Pickton et al., 2007).* Conversely, Kansas DOT sponsored a study that used an input/output model to approximate direct, indirect, and induced output, income, and employment of the Kansas Comprehensive Transportation Program from 1999 to 2004. This study did not consider user benefits *(Babcock, 2004).*

Economic performance measurement should differentiate between net growth and redistribution of wealth. Though the literature overwhelmingly asserts that transportation investments have a positive and significant impact on economic outcomes, it cautions decision makers to discern between economic growth and redistribution of wealth *(Lewis, 1991; GAO, 2005).* For example, investments targeting congestion in a central business district (CBD) may benefit the CBD only, while investments targeting congestion in an industrial zone or in the suburbs may have positive cascading effects throughout the entire metro area *(Weisbrod et al., 2001).* Congestion reduction efforts greatly benefit companies with highly specialized input and labor requirements and those companies that engage in a great deal of truck shipping. Redistribution of benefits may be spatial, temporal, or socioeconomic in nature *(Lakshmanan and Chatterjee, 2005; Weisbrod et al., 2001).*

Outcome evaluations should be conducted to gauge accuracy of predicted costs and benefits. Though transportation projects are often selected based on perceived indirect benefits, the literature suggests highway and transit projects rarely meet projected outcomes of cost and usage. It is likely they fall short of achieving indirect benefits as well, but outcomes of transportation projects are rarely monitored so it is not known for certain. The Federal Transit Administration recently instituted a requirement for before-and-after studies of transit projects funded under New Starts, however, there are no requirements for economic analysis of highway projects because those are funded under a formula program *(GAO, 2005).* Practitioners in the United States can look to other developed countries such as Canada, Australia, Japan, and New Zealand for their use of before-and-after studies *(MacDonald et al., 2004).*

Economic Performance Factors and Objectives

Transportation investments have significant potential economic benefits and impacts that are often considered in analyses of potential capacity expansion projects. Transportation infrastructure plays a vital role in the economy at local, regional, and national levels and investments in this infrastructure provide benefits through improved accessibility, reduced travel times, and similar changes. Infrastructure investments also can disrupt economic activities by restricting access to businesses during construction or taking local businesses as part of right-of-way acquisition. The framework considers two economic factors:

1. **Economic Impacts** – These impacts include monetized user benefits such as travel-time savings and fuel and nonfuel cost savings, improvements in reliability, and safety benefits.
2. **Economic Development** – Economic development captures the broader economic benefits that can accrue as a result of transportation investment. This factor includes productivity effects driven by supply chain improvements, accessibility benefits, and more general macroeconomic impacts such as regional economic output and employment.

The SHRP 2 Capacity program is conducting research into economic factors and potential performance measures as part of the C03 project, Interactions between Transportation Capacity, Economic Systems, and Land Use and Economic Considerations in Project Development. Measures for this section of the framework will be developed as part of the C03 effort.

CHAPTER 7

Community Factors

Background Literature

Transportation improvements can enhance quality of life in a variety of ways, but only if planned, designed, constructed, and maintained with appropriate sensitivity to existing communities and the environment *(Cambridge Systematics, Inc., 2002c)*. Several interrelated concepts highlight methods and practices that transportation practitioners can use to achieve positive results for both the transportation systems and communities they serve. These concepts include context sensitive solutions (CSS) (also referred to as context sensitive design), environmental justice, and the transportation and land use relationship.

CSS is an approach to increasing safety and mobility of transportation facilities while preserving scenic, aesthetic, historic, environmental, and community values. A 1998 national conference titled "Thinking Beyond the Pavement" brought together transportation practitioners of all specialties and private sector and citizen stakeholders to discuss how to:

- Integrate highway development with communities and the environment while maintaining safety and performance;
- Encourage continuous improvement; and
- Achieve flexible, context sensitive design in all projects.

Several key reports review the history and legislative backing for CSS, terminology, recent CSS activities, and general frameworks for implementation *(Neumann et al., 2002; Flexibility in Highway Design, 1997; Cambridge Systematics, Inc., 2002c)*.

While CSS focuses on harmonizing transportation projects with communities and the environment, environmental justice considers the distribution of benefits and burdens across space, social groups, and time. Environmental justice performance measures are often the same as performance measures in other categories (e.g., mobility, accessibility, safety, impacts on human health, and the environment) but are distinguished for different population groups. Environmental justice considerations are required as part of the NEPA process during the project development stage but also are found earlier in the state and regional transportation plans. The literature concerning environmental justice covers legislative and regulatory requirements, types of considerations, methods, and processes to determine outcome equity, and evaluation techniques *(Forkenbrock and Sheeley, 2004; Cambridge Systematics, Inc., 2002a; Cambridge Systematics, Inc., 2002b)*.

Just as CSS and environmental justice require nontraditional partnerships with resource agencies and community stakeholders, capitalizing on relationships between transportation and land use requires collaboration between transportation agencies and municipalities. Decisions concerning transportation and land use have historically been made in a related, but nonintegrated, fashion. The NEPA process requires a review of land use impacts in the environmental impact statement (EIS), and beginning with the Intermodal Surface Transportation Equality Act (ISTEA), federal legislation requires consideration of land use impacts. Interest in integrated planning efforts, including access management, mixed-use development, transit-oriented development, and smart growth has subsequently grown throughout the transportation industry over the last decade *(Cervero et al., 2004; Cambridge Systematics, Inc., 2004; Parsons Brinckerhoff Quade & Douglas, Inc., 1998; Rose, 2005)*.

Several efforts have attempted to provide guidance for quantitatively measuring community impacts of transportation projects and their distribution among segments of the population *(TransTech Management, Inc., 2004; Forkenbrock and Weisbrod, 2001; Cambridge Systematics, Inc., 2002a; The Louis Berger Group, Inc., 2002; Ward, 2005; Cambridge Systematics, Inc., 2004; Edwards, 2004)*. Quantitative models (requiring the use of input measures) are used to predict transportation and land use interactions *(ICF Consulting, 2005)*. Several common measures of community impacts are:

- Number of residents exposed to noise in excess of established thresholds;

- Number of opportunities within a specific distance on a specific mode; and
- Results of visual preference surveys.

Measures also may focus on the process used to arrive at context sensitive solutions and distribute them about the community. Examples are:

- Use of multidisciplinary teams;
- Measures of public engagement; and
- Definition and adherence to vision, goals, and objectives *(TransTech Management, Inc., 2004).*

Key Findings

Although measures are defined in the literature, several challenges to measurement of impacts and distribution of impacts within communities remain. These issues are summarized in the remainder of this section.

Comprehensive assessments of community effects of proposed transportation projects are inherently complex. It is difficult to balance benefits to users and effects on other community residents, and even among community residents numerous competing effects must be traded off. Various segments of the community may be affected quite differently, and people vary in their preferences and opinions, so outcomes desirable to some may be unacceptable to others. Effects such as visual quality or community cohesion are difficult to measure objectively. Methods such as stated-preference surveys, artist sketches, and GIS-based approaches, however, may be used by practitioners to incorporate qualitative factors into the transportation planning process *(Forkenbrock and Weisbrod, 2001; Forkenbrock and Sheeley, 2004; Cambridge Systematics, Inc., 2002a).*

Participation by a wide range of stakeholders is vital for defensible, responsible, equitable, and successful outcomes of the transportation planning process. What may not appear critical to a transportation analyst may be crucial to a neighborhood or population subgroup. Some agencies have noted that increased public outreach efforts have identified issues not previously identified as concerns to local communities. Similarly, inclusiveness in land use and transportation planning, design, and implementation is essential to successful projects. Outreach diminishes the likelihood of a NIMBY backlash and gives residents of an affected area a vested stake in ensuring that what is built is consistent with neighborhood goals *(Forkenbrock and Weisbrod, 2001; Forkenbrock and Sheeley, 2004; Cervero et al., 2004; Cambridge Systematics, Inc., 2002a).*

Flexible design, public participation, and high-quality implementation help achieve goals of individual communities. Communities have individual requirements for transportation infrastructure design, but designers have historically relied on a one-size-fits-all approach (propagated by conservative use of industry-wide manuals such as AASHTO's Green Book and related state highway design standards). Recognizing this, in 1997, the FHWA published its *Flexibility in Highway Design* manual to encourage designers to consider community values and more liberal consideration of the manuals in their designs. In 2004, AASHTO followed suit by releasing *A Guide for Achieving Flexibility in Highway Design.* Both guides emphasize community input into the design process *(Flexibility in Highway Design, 1997; A Guide for Achieving Flexibility in Highway Design, 2004).*

Institutional impediments to performance measurement may be overcome. Complexities accompany coordination of activities among multiple actors and stakeholder groups with divergent interests. One potential solution is to create a champion to guide development, implementation, and reporting of measures. The champion should be someone familiar with the principles of social impacts, distribution of impacts, or relationships between transportation and land use *(TransTech, 2004; Cervero et al., 2004).* Another solution is to create a Memorandum of Understanding (MOU) among collaborating agencies and organizations, modeled after the MOU signed by 23 state agencies in support of the Efficient Transportation Decision-Making system *(Edwards et al., 2005).*

Community Performance Factors and Objectives

Highway capacity projects can have both positive and negative impacts on the physical and social characteristics of a local community. Because the valued characteristics of a community are often subjective, the impacts (both positive and negative) must be evaluated collaboratively, with input provided from residents, local business owners, and other interested stakeholders. The measurement of community impacts should be grounded in local and regional land use and transportation plans that establish a clear vision for a community. Although there are several potential ways to classify community impacts, the following four categories are used to differentiate among the key concepts in this part of the framework:

- Land Use;
- Archeological, Historical, and Cultural Resources;
- Social; and
- Environmental Justice.

Land Use

Land use impacts include changes in land cover and vegetation, changes in the use of land from natural to human uses, and changes in the type of use (e.g., residential, commercial, industrial, agricultural). The change in land use can be reflected in the environmental quality of the land, the type of human use, and the intensity of use. Highway capacity projects can impact land use through direct physical impacts on the land, or indirect impacts resulting from new levels of mobility and accessibility. Two broad objectives in the land use factor area are supported by the five framework measures in Table 7.1:

- Land preservation; and
- Integration of land use and transportation planning efforts.

The case study highlight illustrates how the Puget Sound Regional Council measures the consistency of induced land consumption with the relevant land use plans in their Vision 2040 plan.

Archeological, Historical, and Cultural Resources

Communities often have an interest in preserving their past to maintain a sense of history, offer educational opportunities, and support research. Highway capacity projects can threaten preservation efforts directly, by impacting historic, cultural, and archeological sites, or indirectly, by changing the usage

SHRP 2 Framework Measure	Specific Measure Applications
Transportation Land Consumption – Amount of land converted to transportation uses.	• Land needed for new facility and right-of-way by type (e.g., agricultural, forest, wetland, urbanized land); • Acres of farmland directly impacted; • Encroachment on developed lands – number of residential, commercial, public, and mixed use property impacts; and • Acres of right-of-way acquisitions.
Induced Development Land Consumption – Amount of land developed for nontransportation uses as a result of the project.	• Amount of land projected to be consumed due to economic growth related to project (based on model).
Consistency of Induced Land Consumption with Land Use Plan – Extent to which anticipated induced growth impacts are consistent with local and regional plans for growth.	• Projected growth (based on models) due to project are in line with local and regional vision and plans; • Development guidelines and requirements (zoning codes, development incentives, etc.) are consistent with local and regional plans; • Miles of residential streets with significant ‘traffic conflicts’ (frequent access points, etc.) measured using a level of service scale (A to F); and • Miles of arterial streets with significant ‘land use conflicts’ (frequent driveway spacing, etc.) measured using a level of service scale (A to F).
Support of Project for Growth Centers – Project serves designated growth centers or growth policy areas.	• Project is located within the boundaries of a designated growth center; • Project directly serves a designated growth center; and • Local jurisdictions are permitting housing units in a manner consistent with the regional growth strategy – distribution of issued housing permits, by regional geography, by county.
Local-Regional Plan Consistency – Consistency of local land use policies with regional transportation-land use vision.	• Project is consistent with local and regional land use policies; and • Land use – transportation compatibility index: defined as daily traffic divided by average residential or commercial driveway spacing.

Case Study Highlight: Puget Sound Regional Council (PSRC) Vision 2040

Description: PSRC’s long-range transportation plan, Destination 2030, and regional transportation/land use plan, Vision 2040, were developed using an extensive array of performance measures addressing mobility, safety, land use, the environment, and other issues. The agency has implemented performance monitoring systems to continue to track transportation and land use trends in the region. Projects included in the region’s TIP must be included in, or consistent with, Destination 2030.

Sample Measure:

- Outcome – Local jurisdictions are permitting housing units in a manner consistent with the Regional Growth Strategy;
- Measure – Distribution of issued housing permits by regional geography and by county, in order to assess jobs-housing balance and other issues; and
- Data Source – PSRC Housing Permit Database.

Table 7.1. Community Measures – Land Use Factor

around these sites to impact the access and experience of a visit to the site. The efforts to incorporate these considerations fall broadly under two objectives:

1. Preserve sites of archeological or historical significance; and
2. Preserve research opportunities.

Table 7.2 displays the two framework measures, supported by specific example measures. The case study highlight illustrates how Florida DOT uses their Environmental Screening Tool to measure site location.

Social

Impacts on the social aspect of communities range from aesthetics and noise to displacement and fragmentation. Highway capacity projects can impact these factors through the built form of the infrastructure or the effects of construction or operation of the facility. Two objectives generally link the measures with a community's social issues and concerns:

- Preserve and promote safe and vital communities; and
- Promote projects that are supported by the community.

The social factors are supported through five framework measures, as listed in Table 7.3. The case study highlight demonstrates how Florida's Sociocultural Effect Evaluation is used to measure community cohesion.

Environmental Justice

In addition to evaluating overall transportation, economic, environmental, and community impacts, transportation agencies must consider the differential impacts of the various factors considered in this framework on traditionally disadvantaged groups, defined by race, ethnicity, income, or mobility impairment. Therefore, these measures tend to be similar to those found in other factor areas, but are analyzed specifically with respect to these disadvantaged groups to ensure they are not carrying a disproportionate load of the negative impacts of capacity projects. A single objective describes the goal of this factor: fair and equitable distribution of transportation benefits and costs. Table 7.4 presents the framework measures. The example measures provide a good overview, but most measures found throughout this framework could be considered from the environmental justice perspective. The case study highlight illustrates how Columbus Ohio's Regional Transportation Plan measures environmental justice.

Community Data Gaps and Opportunities

Land Use

This factor covers assessment of consistency with existing land use plans and policies, as well as assessment of land consumed by projects or programs of projects – both directly due

SHRP 2 Framework Measure	Specific Measure Applications
Site Location – Net loss of sites with archeological or historical significance.	• Acres of land with archeological or historical significance consumed by project; • Impact of project on public access to sites with archeological or historical significance; • Number of archeological and historic sites that are not satisfactorily addressed in project development before construction begins; and • Number of historic resources avoided or protected as compared to those mitigated.
Artifact Location – Project impact on the location of historic artifacts providing research opportunities.	• Acres of land containing historic artifacts required by project; and • Impact of project on access to sites with historic artifacts providing research opportunities.

Case Study Highlight: Florida's Environmental Screening Tool

Description: Florida DOT (FDOT) is in the process of screening all proposed highway capacity needs projects using the Efficient Transportation Decision Making (ETDM) process. The ETDM process aims to improve and streamline the environmental review and permitting process. As part of the ETDM, FDOT implemented an internet-accessible interactive database tool called the Environmental Screening Tool (EST). EST performs standardized environmental impact analyses and reports comments about potential project effects. The EST is a semi-automated, GIS-enabled application that analyzes any proposed corridor and adjacent areas in any part of Florida for major environmental flaws and other impacts. FDOT has developed a performance measurement process to monitor the effectiveness of the program.

Sample Measure:

- Activity – Protection of Cultural Resources;
- Measure – Total number of other findings of "effect" on which opinions are provided need State Historic Preservation Office input; and
- Targets – Baseline to be established.

Table 7.2. Community Measures – Archeological and Historic Resources Factor

SHRP 2 Framework Measure	Specific Measure Applications
Community Cohesion – Change in physical neighborhood-level connections that unite residents and businesses.	• Number of homes and businesses to be relocated due to project; • Forecasted change in walking trips; • Change in travel times to neighborhood points of congregation; • Key pedestrian routes severed as a result of project; and • Key pedestrian routes reconnected as a result of project.
Noise – Change in noise level in vicinity of project during and after construction.	• Increase in noise levels on schools, churches and public gathering places; • Number of noise receptor sites above threshold; • Number of residences exposed to noise in excess of established thresholds; • Percent of population exposed to highway noise above 60 decibels; • Noise level exceeded 10 percent of the time during specified hours, measured in "A-weighted" decibels (dBA). This measure also can be spatially oriented (e.g., number of homes where L10 is greater than 50 dBA) and/or expressed as a change (e.g., L10 increases by greater than 10 dBA); and • Constant equivalent noise level (when levels actually vary), measured in "A-weighted" decibels (dBA). This measure also can be spatially oriented (e.g., number of homes where the equivalent continuous noise level (Leq) is greater than 50 dBA) and/or expressed as a change (e.g., Leq increases by greater than 10 dBA).
Visual Quality – Change in visual characteristics that define community identity.	• Number of homes or other buildings from which project will be visible. • "Major landmarks" blocked from view by project from a significant vantage point. • Color Rating Matrix. Measure of both color and reflectivity, with scores assigned from a matrix. Scores are based on compatibility with the natural landscape, with compatible colors and low reflectivity receiving the highest score. (Tahoe RPA scenic shoreline assessment). • Texture Rating Matrix. Measure of both the texture of individual surfaces, as well as the total number of separate planes (surfaces) on a structure, with scores assigned from a matrix. Heavier texture and greater number of planes receive the highest scores. • Perimeter Screening. Percentage of perimeter (rooflines, retaining walls, bridges, patios, etc.) screened by natural vegetation or similar native object, as viewed from 300 feet offshore.
Emergency Response Time – Change in time required by fire, police, and medical responders to reach a community.	• Current emergency response time versus predicted (modeled) emergency response time after completion of project; and • Percent of population which perceives that response time by police, fire, rescue or emergency services has become better or worse and whether that is due to transportation factors.
Citizen's Concerns – Transportation-related issues of greatest concerns to citizens.	• Project addresses issues of greatest concern to citizens demonstrated through public outreach and market research; and • Percent of population that perceives that its environment has become more 'livable' over the past year with regard to ability to access desired activities.

Case Study Highlight: Florida's Sociocultural Effect Evaluation (SCE)

Description: Florida DOT's SCE evaluation process seeks to analyze any effects that a potential transportation investment would have on the quality of life in the communities surrounding that project. The process integrates qualitative and quantitative analysis through the use of surveys, public meetings, windshield surveys, and GIS analysis of local amenities and characteristics. The analysis is custom tailored to each proposed project, selecting relevant issues from six broad categories: Social, Economic, Land Use, Mobility, Aesthetics, and Relocation.

Sample Measures:

- Would the project result in any barriers dividing an established neighborhood or would it increase neighborhood interaction?
- Would the project result in any loss, reduction, or enhancement of connectivity to a community or neighborhood activity center(s)?

Table 7.3. Community Measures – Social Factor

SHRP 2 Framework Measure	Specific Measure Applications
Environmental Justice – Relative distribution of project benefits and costs across affected population.	• Change in access to jobs and markets for disadvantaged populations compared to entire population; • Change in person-hours of delay for disadvantaged populations compared to entire population; • Change in noise levels for disadvantaged populations compared to entire population; • Change in air quality for disadvantaged populations compared to entire population; • Change in sidewalk connectivity for disadvantaged populations compared to entire population; • Percent of region's unemployed or poor who cite transportation access as a principal barrier to seeking employment; and • Environmental justice cases that remain unresolved over one year.

Case Study Highlight: Columbus, Ohio Regional Transportation Plan – EJ Analysis

Description: The Mid-Ohio Regional Planning Commission (MORPC) has conducted environmental justice (EJ) analysis of recent long-range transportation plans with a strong reliance on accessibility measures. MORPC has three key objectives for their EJ analysis: ensure adequate public involvement of low-income and minority populations, assess adverse impacts on low income and minority populations, and assure that low-income and minority populations receive a proportionate share of benefits. Measures were developed from MORPC's travel demand forecasting model.

Sample Measures (based on analysis of locations of EJ populations, and in comparison to non-EJ populations):

- Average number of accessible job opportunities;
- Percent of population close to a college;
- Average travel time for work trips; and
- Displacement from highway projects.

Table 7.4. Community Measures – Environmental Justice Factor

to the project footprint(s) and indirectly related to impacts of induced development. Direct impacts of projects on land use can be evaluated based on land cover data and orthophotography (which combines the image characteristics of an aerial photograph with the geometric qualities of a map) available from federal, state, and local sources. Land use forecasting models can be used to assess impacts for future scenarios.

Data gaps for this factor include:

- Inconsistency in the format of land use data across multiple jurisdictions, which can preclude aggregation across sources for efficient analysis;
- Availability of development tracking systems to keep land use data current and to evaluate actual growth patterns in a timely fashion; and
- Accuracy of methods and models for forecasting future land use and induced development from transportation improvements.

Data improvements for the land use area include:

- Use of remote sensing to develop or fill gaps in land use data;
- Use of satellite imagery for routine verification of land use changes;
- Development and agreement on data standards for land use classifications;
- Regional land use data integration efforts with updating mechanisms; and
- Development of model agreements to provide the necessary value proposition and disclosure protections to enable public use of privately maintained land use data.

Archeological and Historical Sites

DOTs must evaluate potential impacts of highway projects on historic and cultural resources, and on Native American trust resources or sacred sites – as required by NEPA and Section 106 of the National Historic Preservation Act (NHPA). Information on these sites can be obtained from the National Register Information System, State Historic Preservation Offices, and some Department of Defense agencies that manage historic properties under Section 110 of NHPA. In addition, some DOTs have developed cultural resources databases. Information on archeological sites is both less frequently available and also more difficult to obtain in advance of project construction. There has been some success with region-specific models that predict locations of sites based on topography, vegetation, climate, and known characteristics of ancient populations.

Because discovery of impacts to significant sites following project programming can result in delays, added costs, and negative stakeholder relations, tools that bring available information together in a comprehensive fashion for use at the long-range planning and preprogram stages would be of great value. Integration of cultural resource, environmental, land use and transportation data would provide a single platform for advance planning and screening analysis. Though many states have the capability to overlay multiple GIS layers, few have integrated this information within an analysis context. Florida's Environmental Screening Tool (EST) provides a model for how this might be done.

Social

This factor includes a widely varied mix of measures, including consideration of capacity project impacts on community cohesion, noise, visual quality, emergency response time, and citizen concerns. With the exception of noise impacts (which are a required consideration under the NEPA process), these impacts are not typically captured or reported in a systematic way. Community cohesion impacts have been addressed through description of neighborhood boundaries and pedestrian routes, quantification of homes relocated or changes in pedestrian travel times, and use of market research techniques to assign scores to project alternatives based on stated preferences. This analysis utilizes available data on population, housing, and business location from the census or local source, land use and tax assessment data sets, neighborhood association meeting records. Walking trip data and model results also may be used.

Noise impacts are analyzed using information on current traffic characteristics, population and housing, pavement data, sound barrier data, and field surveys of current noise levels. FHWA's Traffic Noise Model is used for forecasting.

Emergency response time impacts can be assessed using existing data on Emergency Medical Services (EMS) districts and emergency vehicle dispatch locations, current EMS response times, and travel demand models or GIS-based tools to assess impacts of changes in the transportation network on travel times.

Methods for measurement of visual quality impacts are not well developed, though approaches may include identification of current visual characteristics of note (e.g., ground cover, land contours, locations of major landmarks) or scoring of existing or proposed structures based on adherence to accepted visual standards.

Identification of the extent to which a project addresses citizen concerns and priorities may be accomplished via surveys or community outreach efforts, or market research techniques used to derive priority scores for alternatives.

This factor requires extensive project-level data gathering. Specific data gaps include availability of current and forecasted pedestrian movements, information on business locations and neighborhood boundaries, and current EMS response times. Potential investments include development of complete and up-to-date land use data sets (utilizing assessors' records or zoning maps in urbanized areas and remote sensing in sparsely populated areas), and coordination with local EMS agencies as part of project stakeholder outreach activities to obtain current information.

Environmental Justice

Environmental justice (EJ) is not a stand-alone performance measure, but rather a means to assess the differential impacts (across multiple measures) of capacity projects on various population groups. EJ assessments depend on use of GIS analysis tools to relate impact measures (e.g., noise levels, delay access to jobs) to demographic information. Use of "select link" analysis within network models also is an important method for understanding how project benefits and costs impact different traveler groups based on origins and destinations. Data sources needed to support EJ analysis include state and MPO socioeconomic data sets, supplemented with census data. Travel demand models derived from recent household survey data also can provide valuable information on traveler origins and destinations, allowing for linkage with socioeconomic information. Though EJ analysis is typically straightforward, one opportunity to improve the efficiency and coverage of analysis would be to make data on race, ethnicity, and mobility-impaired groups available for traffic analysis zones.

CHAPTER 8

Cost Factors

Background Literature

The importance of high-quality, comprehensive project cost estimates cannot be overstated. Although cost is not typically considered a performance factor to be used in comparing capacity projects, it is a critical tool in selecting and prioritizing agency projects, especially given limits on available funding. Transportation agencies have developed a range of methods to estimate and compare the cost of project alternatives.

Key Findings

The literature on cost estimation makes the following points.

It is important to examine project costs early and often. Project costs can escalate unexpectedly for a variety of reasons, some controllable and others unavoidable. Therefore, it is critical that project costs be monitored closely so that those that are avoidable can be controlled, and those that must be dealt with are identified early and then accounted for in budgeting. NCHRP 20-24, Task 37A: *Comparing State DOTs' Construction Project Cost and Schedule Performance – 28 Best Practices from 9 States* (2007), compares cost and schedule performance at nine state DOTs and identifies techniques important to achieve success, including: tracking cost performance early and often to maintain accountability and pinpoint when and why problems occur; using a standardized coding system to track the causes of cost overruns; linking performance to pay and use value engineering; and holding contractors accountable (for example, by preventing contractors from bidding if they frequently have cost overruns).

Potential external influences on costs need to be considered and monitored. Engineers typically do not consider potential community concerns or other exogenous influences on project cost, choosing to focus on the direct engineering and transportation considerations of a project. Higher-quality cost estimates should account for outreach and engagement with project stakeholders to help avoid potential increases in costs due to challenges to the project or increased time for project development and construction. Community outreach at early stages of a project can help a transportation agency understand potentially sensitive issues and to build considerations for project delay into cost estimates.

Consideration of public concerns, environmental conflicts, and public outreach can improve cost estimates. Opposition to a project, regardless of its nature or merit, can significantly increase costs, including the cost of redesigning or abandoning a project after completing significant preliminary work. Consideration of public concerns and inclusion of such issues *earlier* in the process, before cost estimates are included in official documents (planning studies and state or regional transportation improvement programs), can offset costs later on. NCHRP Report 574: *Guidance for Cost Estimation and Management for Highway Projects During Planning, Programming, and Construction* (2006), recommends a set of strategies for cost estimation and management to better identify risks and conflicts, ensure consistency, and maintain integrity throughout the process.

Each of the factors included in the performance measurement framework will impact project cost, both through increased initial screening and analysis and subsequent mitigations or redesign as a result of project impacts. DOTs should incorporate these analytical costs in early project cost estimates or maintain a supply of project-independent funds to cover analysis costs. Early use of screening measures will help DOTs identify potential mitigation requirements or project alternations that will produce more reliable cost estimates and better informed investment decisions.

Cost Performance Factors and Objectives

Quality cost estimates that remain stable through the planning and programming phases of project development, and that incorporate both direct and indirect costs of a project,

SHRP 2 Framework Measure	Specific Measure Applications
Cost Stability – Change in cost estimates during the project development process.	• Percentage change in cost estimates at milestones (e.g., planning, preliminary engineering, partial design, final engineers estimate, project letting); and • Absolute change in cost estimates at milestones (e.g., planning, preliminary engineering, partial design, final engineers estimate, project letting).
Construction Cost Escalation Factor – Change in price index or key construction material costs.	• Projected increase in cost based on recent and historic trends in cost escalation.
Case Study Highlight: Washington DOT Transportation Project Mitigation Cost Screening Matrix **Description:** The Transportation Project Mitigation Cost Screening Matrix or "screening tool" is a tool that helps transportation planners identify proposed projects that may benefit from the application of watershed-based mitigation. The screening tool analyzes readily-available data on urbanization, floodplain areas, soil types, topography, wetlands, hazardous materials, parks, and other cultural resources. Projects that encounter these features commonly have the highest environmental mitigation costs, especially for stormwater treatment and wetlands replacement. The tool generates a "mitigation risk index" or "MRI" consisting of a single score that estimates the percentage of land area within the project limits that will likely experience logistical difficulties or elevated costs for in right-of-way environmental mitigation. Sample Measure: • Mitigation cost of type of wetlands, relative to other project alternatives (e.g., forested wetlands are difficult to mitigate in a technically sound and cost-effective manner).	

Table 8.1. Cost Measures – Cost Factor

are crucial to making informed decisions. Two broad cost factors have been identified for this effort:

- Cost and
- Cost-Effectiveness.

Because cost is not typically used as a separate performance measure, the information provided in this section is not as fully developed as other factors. Other SHRP 2 projects, such as C01, *A Framework for Collaborative Decision Making on Additions to Highway Capacity*, are developing additional information that will be incorporated into this discussion at a later date.

Cost

This factor addresses cost estimation management and practice. Issues addressed include the reliability of cost estimates, incorporating unforeseen costs (resulting from external influences), and improving accountability for early cost estimates. Sound cost estimation practices and successful execution of measures in this factor will support the evaluation of measures in the Cost-Effectiveness factor. The objective defined for these measures is: reduce the incidence of cost variability. The framework includes two measures, supported by example measures, as shown in Table 8.1. The case study highlight illustrates how Washington State DOT's Transportation Project Mitigation Cost Screen Matrix is used to capture the cost of mitigation efforts.

Cost-Effectiveness

This factor includes traditional aggregate measures of cost-effectiveness such as unit construction cost; productivity or cost indices; analyses of federal/local funding matches and public-private partnerships; as well as more analytical benefit/cost analyses, including techniques for monetization of non-traditional measures. Three broad objectives are supported by the measures in the framework:

1. Select transportation projects with the greatest benefit relative to cost;
2. Develop projects efficiently; and
3. Encourage partnerships in funding transportation projects.

The framework includes six different measures that capture aspects of cost-effectiveness, as shown in Table 8.2. The case study highlight illustrates how the Denver Regional Council of Government's 2008-2013 Transportation Improvement Program measures the benefit/cost of proposed projects.

SHRP 2 Framework Measure	Specific Measure Applications
Benefit/Cost (B/C) Analysis – Monetized project benefits relative to total project costs.	• Cost/benefit of existing facility versus new construction for travel-time savings, etc.
Project Unit Cost – Total project cost per unit of project delivered.	• Cost of project per lane-mile, centerline mile, user of facility, etc.
Qualitative Cost-Effectiveness – Benefits achieved across measures per dollar of cost.	• Cost per hour of travel time saved; and • Cost per water quality benefits or impact.
Construction Productivity Index – Percentage of total project cost for administrative and change order costs.	
Local/Regional Match – Percent of project costs absorbed by local or regional agencies.	• The share of project expenses beyond requirements that are paid for by local or regional governments.
Private Investment – Private investment in complementary infrastructure.	• Ratio of private investment to public investment; and • Change in benefit due to private investment.

Case Study Highlight: Denver Regional Council of Governments FY 08-13 TIP

Description: DRCOG's project evaluation process for its latest Transportation Improvement Program (FY 2008-2013) includes a unique scoring system for each type of project, including roadway capacity. The scoring system is categorized into 10 topics: current congestion, safety, cost-effectiveness, condition of major structures, long range plan score, transportation system management, multimodal connectivity, matching funds, project-related Metro Vision implementation and strategic corridor focus, and sponsor-related Metro Vision implementation. Each category has a unique scoring system, and receives up to 15 points depending upon how that category is weighted. Project sponsors submit their project online, complete this ranking process, and are given an instant score. This gives them a sense of how their project will compare to others, and what areas they need to improve in order to increase the chances for funding.

Sample Measure – Based on the project's current forecast cost per daily person-miles-of-travel (PMT), up to 10 points will be awarded as follows:

- For bus/HOV/BRT, roadway widening, and new projects: 10 points will be awarded to projects with a cost per PMT of $50 or less; 0 points to projects with a cost per PMT of $550 or more; with straight line interpolation between.
- For interchange reconstruction and new interchange projects: 10 points will be awarded to projects with a cost per PMT of $250 or less; 0 points to projects with a cost per PMT of $2,750 or more; with straight line interpolation between.
- PMT for new road and interchange projects based on modeled usage estimates.

Table 8.2. Cost Measures – Cost-Effectiveness Factor

CHAPTER 9

Conclusions – Using Measures in Decision Making

The previous sections of this report described the development of the performance measurement framework, related performance measures, and the key data sources currently used and needed to support those measures. Ultimately, the investigation of performance measures for the SHRP 2 Capacity program is focused on providing information to a data-driven, collaborative decision-making process. This concluding section begins to address the question of how to best link performance measures to the collaborative decision-making framework being developed in SHRP 2 C01.

Links to Decision Making

Chapter 3 provided broad outlines of how performance measures can help inform decisions at various phases of the process. This chapter attempts to make more specific links, both to key decision points and across the key phases of the project development process.

Key Decision Points for Performance Measures

The SHRP 2 C01 project has identified several phases of the project development process within which key decisions are made, including long-range planning, programming, corridor studies, environmental review, and permitting. For each of these, the C01 project has identified several key decision points. Table 9.1 identifies the links between the collaborative decision-making framework and the performance measurement framework. Three types of links are described:

1. **Select Factors –** The performance measurement framework is organized around several high-level planning factors. For each of the key phases, it is important to identify which of these factors are under consideration.
2. **Select Measures –** Within the identified factors, specific measures should be selected that help address the specific concerns of the agency or agencies evaluating a new capacity project.
3. **Use Measures –** After selection of the measures, they should be used to evaluate specific projects.

Several key concepts from within the table warrant more detailed explanation, including:

- **Consistency Analysis –** One of the key uses of performance measures for project analysis is as a tool to evaluate how proposed investments by a transportation agency conform to existing plans and studies in other areas. Land use, water, wildlife, and other similar plans help form the context within which DOTs make decisions. For some issues, such as air quality, a specific determination of conformity is required, through which expected contributions to criteria pollutants are modeled. Consistency suggests a more qualitative assessment. Examples could include the extent to which proposed investments are in areas that have an established regional transportation-land use vision or a determination if a project is within a vital area for wildlife or water quality, as defined by a habitat or water quality plan.
- **Screening Process –** At several linkages a screening process is suggested. At the long-range planning level, this process is used to qualitatively assess a plan's impact on broad planning factors (e.g., positive or negative impacts on mobility, water quality, etc.). At more detailed levels, the screening process uses measures to evaluate how individual projects or project alternatives will actually impact these factors.
- **Red Flag Analysis –** Agencies can use measures to identify segments of road with known environmental or community concerns. Some agencies maintain a 'red map' of roads to which adding capacity is simply not feasible. Using measures to flag challenging projects early in the process can lead the agency to focus on projects that can be developed easier and faster or to identify when extraordinary

Key Decision Point		Linkage	How Measures Influence Decision Making
Long-Range Planning			
202	Approve Vision and Goals	Select factors	• Vision and goals of the LRP should define the universe of performance factors considered.
203	Approve Evaluation Criteria and Methodology	Select measures	• Measures are selected from within the factors identified in 202; and • General statewide or regional targets should be set collaboratively for measures.
204	Approve Transportation Deficiencies	Use measures	• Use targets set in 203 to determine deficiencies in the state or region; • Environmental PMs used in geospatial analysis of potential 'fatal flaws' for significant natural resources; and • Transportation PMs define level of need (i.e., funding required to achieve targets set in 203).
207	Approve Plan Scenarios	Use measures	• PMs used in a screening process for plan scenarios.
Programming			
301	Approve Evaluation Criteria and Methodology	Select measures	• Measures selected for consistency analysis (i.e., are the set of projects programmed consistent with the vision and goals set in 202); and • Measures selected for prioritization algorithm – readily available data and quantifiable.
302	Approve Project Priority List	Use measures	• Use consistency process or prioritization algorithm to prioritize and select projects.
304	Adopt Conformity by MPO	Use Measures	• Air Quality measures support this process; and • Potential future 'conformity' or consistency processes for GHG emissions or other natural resources.
Corridor Studies			
403	Approve Goals for the Corridor	Select factors	• Goals should be consistent with those developed in 202; and • Goals for the corridor study define the universe of performance factors considered.
404	Approve Evaluation Criteria and Methodology	Provide measures	• Measures are selected from within the factors identified in 403; and • Reasonable range of expectations set for each measure (i.e., what is the best that can be done for congestion or what is the worst allowable impact).
407	Approve Range of Alternatives	Use measures	• Measures used within a high-level screening process to identify feasible alternatives (i.e., those without fatal flaws).
408	Adopt Preferred Alternative	Use measures	• Measures used at a more detailed level to evaluate a narrower range of alternatives in greater depth.
Environmental Review			
503	Approve Purpose and Need	Use measures	• Minor – inform the purpose and needs with performance analysis of the suitability of the proposed solution.
504	Reach Consensus on Study Area	Select measures	• Identify measures that can address the appropriate scale (e.g., corridor, watershed, ecosystem, etc.) relevant for the review.
505	Approve Evaluation Criteria and Methodology	Select measures	• Measures are selected from within the factors identified in 403; and • Specific targets set for measures that require a minimum or maximum regulatory threshold to be met.
507	Approve Alternatives to be Carried Forward	Use measures	• Measures used within a high-level screening process to identify feasible alternatives (i.e., those without fatal flaws).
509	Approve Preferred Alternative	Use measures	• Measures used at a more detailed level to evaluate a narrower range of alternatives in greater depth.

Note: Key Decision Points are taken from SHRP 2 Project C01. Numbers may change.

Table 9.1. Linkages Between Key Decision Points and Performance Measures

public and stakeholder involvement may be required to advance a particularly challenging project.

Linking Performance Measures Across Phases

In addition to linking to key decision points, performance measures should show some consistency across the phases of the project development process. Although measures used in long-range planning may not be the exact measures used in corridor analysis or programming, it is vital that decisions made using performance measures at one phase not be inconsistent with measures used at a later stage.

Performance measures should be refined across scales – from statewide or regional in nature (at the long-range plan level) to corridor or alignment in nature. The key is to define measures broadly in the early stages and more specifically in the later stages. For example, measures of capacity projects at long-range planning stages should be prioritizing among competing corridors for funding by indicating general levels of congestion or identifying red flag issues in corridors that may be stumbling blocks for future project development.

The performance measures framework is designed to help address consistency by identifying high-level measure concepts that can be useful at one or several phases. Table 9.2 presents several examples of specific measure definitions that could be applied during the phases of project development. These are intended to be examples only, not a comprehensive list.

In addition, some performance measures are only relevant during certain phases. For example, the travel-time reliability index requires examination of specific corridors and only has significant use during corridor studies. Similarly, given the often yearly frequency of updates to agencies' Transportation Improvement Programs (TIP), many measures do not apply at this phase. The best case measures for programming are those that evaluate the overall consistency between the proposed program and other major domains, such as land use, water quality, habitat, etc. These measures are qualitative in nature.

Summary of High-Value Opportunities for Data Improvement

Though each factor examined in the previous section has unique data gaps and opportunities, five common themes emerged:

1. Use of remote sensing for data capture;
2. Further development of tailored GIS applications that facilitate use of multiple data layers for specific program and project-level analysis tasks;
3. Further development of modeling and simulation tools that support scenario analysis;
4. Cultivation of stronger interagency partnerships to facilitate data sharing and collaborative approaches to data analysis; and
5. Support for data and metadata standards and data clearinghouses to enable integration of data from disparate sources.

Each of these is discussed in turn below.

Remote Sensing Applications

Remote sensing technology currently is being used to provide a variety of data sets that would be prohibitively expensive to collect via field survey methods. Availability of remote sensing imagery provides valuable baseline information for long-range planning and screening of alternatives. Additional work is needed on specific applications of remote sensing for wetland quality, land use classification, and detailed physical features of land cover. Needs include:

- Data collection (air and satellite photography);
- Image processing software;
- Education and training within the DOT community;
- Development of specific methods for imagery analysis and translation; and
- Development of effective information presentation formats geared to project developers and resource agency partners.

In the short, two activities are needed:

1. Additional targeted research to investigate the potential of remote sensing to produce meaningful data for significant natural resources such as wetlands; and
2. Guidance materials for state DOTs and other transportation agencies to understand how they might use data from remote sensing for specific applications (e.g., wetlands quality monitoring). The effort to produce guidance material might appropriately fall within the purview of the Transportation Research Board, through either the SHRP 2 program or the National Cooperative Highway Research Program (NCHRP).

GIS Applications for Program and Project Analysis

GIS-based tools that incorporate multiple data layers and facilitate specific analysis tasks provide tremendous value to planners and project engineers, eliminating the need to identify and track down data sources and develop custom queries and analysis capabilities. Specific applications where these types of tools would add value include:

- Integrated screening analysis based on transportation, environmental, land use, and cultural resource data;

Factor	Measure	Long-Range Planning	Programming	Corridor Study	Environmental Review
Mobility	Level of service	Percent of state highway miles with level of service E or F, current and projected	Change in project percent of state highway miles with level of service E or F	Percent of corridor highway miles with level of service E or F	Projected improvement in level of service of impacted segments and surrounding highways
Ecosystem, Habitat and Biodiversity	Loss of habitats	Number, size and significance (i.e., endangered status) of habitats adjacent to or overlapping state highways (qualitative measure)	Number or percent of projects in the TIP that may impact habitats of significance	Size and fragmentation of habitats impacted by the corridor	Expected change in habitat size and fragmentation
Water Quality	Water quality protection areas	Number of water bodies on the Clean Water Act Section 303d impaired water bodies list adjacent to transportation infrastructure	Number or percent of projects in the TIP that are adjacent to water bodies on the Clean Water Act Section 303d impaired water bodies list	Distance from highway right-of-way within the corridor to water bodies on the Clean Water Act Section 303d impaired water bodies list, by segment	Distance from highway right-of-way within the corridor to water bodies on the Clean Water Act Section 303d impaired water bodies list, by segment
Climate Change	Infrastructure vulnerability	Percent of or total lane-miles of state highway that are subject to inundation from a severe weather event	Number or percent of projects in the TIP that would be constructed in areas with significant risk of inundation over the life of the project	Expected life of investments in the corridor given the potential for inundation relative to normal expected life cycle	Planned elevation of new infrastructure investment relative to expected level of inundation from a severe weather event
Land Use	Local-regional plan consistency	Percent of municipalities with adopted land use plans that conform to a regional transportation-land use vision	Number or percent of projects within the TIP that are within municipalities that do not have a local land use plan that conforms to a regional transportation-land use vision	Population weighted percent of municipalities in a corridor with adopted land use plans that conform to a regional transportation-land use vision	N/A
Social	Community cohesion	N/A	N/A	Percent of municipalities in the corridor that are divided by highway facilities	Percent of walking trips crossing arterials with a peak period of over 1,000 vehicles per hour

Table 9.2. Examples of Performance Measure Refinement Across Scales

- Provision of a regional overlay of individual agency plans to support cross-agency collaboration on identification of needs and assessment of cumulative resource impacts; and
- Analysis of transportation facility vulnerability related to climate change.

Existing examples of these tools (e.g., Florida's Environmental Screening Tool) can serve as models for development of nationally available capabilities.

Modeling and Simulation Tools

Development of simulation or scenario analysis tools that build on the GIS capabilities described above would provide further value for early exploration of capacity project alternatives. Specific applications of value include:

- Impact assessment for proposed facilities or programs of projects on water quality, habitat, and historic and cultural resources; and
- Analysis of the implications of various climate change scenarios on infrastructure vulnerability.

In the short term, there is an existing Environmental Information Management System (EIMS) developed as part of NCHRP 25-23 project that presents an opportunity to build a decision support tool. This system provides a platform on which environmental management tools could be developed in a consistent manner for use by multiple agencies. The EIMS is being considered as part of AASHTO's Cooperative Software Development Program, but has yet to be adopted.

Interagency Partnerships

Environmental and natural resource agencies at the federal, state, and regional levels offer a wealth of data that are needed to support performance assessments for many of the factors in the SHRP C02 framework. Transportation agencies already are tapping into many of these data sources. Partnerships can be pursued at all levels of government to further strengthen data sharing initiatives, leverage existing monitoring resources, and jointly pursue development of new data sets and tools that meet common needs. Specific examples of successful partnerships include GIS data sharing agreements in Oregon and New York State, and the North Carolina Ecosystem Enhancement Program.

SHRP 2 Project C01 addresses the question of partnerships among multiple agencies to advance the needs of both transportation planning and resource protection. However, that project focuses on providing a framework for collaborative decision making and not a process to actually implement the framework. Additional guidance that identifies model processes to actually implement the Collaborative Decision-Making Framework may make a useful desk reference for agencies. Though it would likely be difficult to provide comprehensive guidance for all of the relevant processes that agencies currently use, it is possible to develop guidance around a common set of processes that apply to many transportation agencies.

Data Sharing

A prerequisite to data integration and sharing across disparate data producers and users is availability of metadata that documents dataset content, derivation, accuracy, and suitability for specific purposes. Use of the federal metadata standards developed by the Federal Geographic Data Committee (FGDC) has become fairly widespread for geospatial datasets. *(Federal Geographic Data Committee)* The FGDC also endorses a variety of other standards for specific data types (e.g., wetlands, vegetation, soils.) Programmatic guidelines and tools that encourage and facilitate provision of complete and consistent metadata would be of value.

Standardization of land use classifications would facilitate sharing of land use data across jurisdictions. Use of the American Planning Association's Land-Based Classification Standards (LBCS) is a promising approach. These classifications could be adopted for use within nationally developed toolsets that include land use data.

Use of existing data clearinghouses for sharing data sets across agencies represents a low-cost, high-value practice. Major clearinghouses at the national level are Geodata.gov and the National Biological Information Infrastructure (NBII). Both sites provide access to a wealth of information resources, and include provision for state and local agencies to share their data. They are supported by well-defined stewardship arrangements and processes for data submittal and updating.

The National Information Exchange Model (NIEM) is another potentially useful resource for support of information sharing initiatives across governments. NIEM is a joint initiative of the U.S. Departments of Justice and Homeland Security. NIEM's function is to "develop, disseminate, and support enterprise-wide information exchange standards and processes that can enable jurisdictions to effectively share critical information in emergency situations, as well as support the day-to-day operations of agencies throughout the nation." NIEM provides a framework within which communities of interest can identify information sharing requirements, develop common standards, and implement the standards through technical tools and training. NIEM currently focuses on criminal justice, public safety, and emergency response data exchange. However, it incorporates several foundational elements of value to any data sharing effort –

including standards for measurement units, and location identification.

In the short term, a more detailed evaluation of existing data standards and available data clearinghouses would provide useful information to form the basis of potential data standards. Following that, it may be useful to pursue a small number of pilot applications or mockups of how a data standard-setting process and clearinghouse would operate. For example, a land use data clearinghouse might have the following steps:

- Adoption of standard land use classifications across jurisdictions;
- Each jurisdiction providing standard metadata and using the clearinghouse to post their data; and
- The DOT accessing these data sets and combining them for use in an analysis.

The pilot applications could help to define these steps and provide the tools to develop the clearing houses within individual states or nationally.

Bibliography

General Use of Performance Measures by Transportation Agencies

Bremmer, D., Cotton, K.C., and Hamilton, B. *Emerging Performance Measurement Responses to Changing Political Pressures at State Departments of Transportation: Practitioners' Perspective.* Transportation Research Board, 2005.

Brown, Mark. *Keeping Score: Using the Right Metrics to Drive World-Class Performance.* Quality Resources, New York, New York, 1996.

Cambridge Systematics, Inc. *NCHRP Report 551: Performance Measures and Targets for Transportation Asset Management.* Transportation Research Board, Washington, D.C., 2006.

Cambridge Systematics, Inc. *NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning.* Transportation Research Board; Cambridge Systematics, Inc., 2000.

Government Performance Project. *Survey Results 2005: Categories, The Agencies.* Government Performance Project, Washington, D.C., Last updated 2007. Available at http://www.gpponline.org. Referenced on July 13, 2007.

Hendren, P.G., Neumann, L.A., and Pickrell, S.M. Linking Performance-Based Program Development and Delivery. Report of a Conference, Irvine, California, August 22-24, 2004. *Second National Conference on Performance Measures (*36) (2005), pages 121-130. Available at http://onlinepubs.trb.org/onlinepubs/conf/CP36.pdf.

Kassoff, H. (2001). Implementing Performance Measurement in Transportation Agencies. Report of a Conference, Irvine, California, October 29-November 1, 2000. *Performance Measures to Improve Transportation Systems and Agency Operations* (2001), pages 47-58. Available at http://www.trb.org/publications/conf/reports/cp_26.pdf.

Larson, M.C. Organizing for Performance Management. Report of a Conference, Irvine, California, August 22-24, 2004. *Second National Conference on Performance Measures (*36) (2005), pages 99-120. Available at http://onlinepubs.trb.org/onlinepubs/conf/CP36.pdf.

Meyer, M. Measuring That Which Cannot Be Measured – At Least According to Conventional Wisdom. Report of a Conference, Irvine, California, October 9-November 1, 2000. *Performance Measures to Improve Transportation Systems and Agency Operations* (2001), pages 105-125. Available at http://www.trb.org/publications/conf/reports/cp_26.pdf.

Padgett, R. *NCHRP 8-36, Task 47: Effective Organization of Performance Measurement.* Transportation Research Board, Washington, D.C., 2006.

Performance Measurement Exchange. *Performance Measurement Exchange.* Federal Highway Administration, Washington, D.C. Last updated July 13, 2007. Available at http://knowledge.fhwa.dot.gov/cops/p.m..nsf/home. Referenced on July 13, 2007.

Performance Measures to Improve Transportation Systems and Agency Operations. Report of a Conference, Irvine, California, October 29-November 1, 2000. *Performance Measures to Improve Transportation Systems and Agency Operations* (2001), 227 pages. Available at http://www.trb.org/publications/conf/reports/cp_26.pdf.

Pickrell, S., and Neumann, L. Use of Performance Measures in Transportation Decision-Making. Report of a Conference, Irvine, California, October 29-November 1, 2000. *Performance Measures to Improve Transportation Systems and Agency Operations: Summary of the Second National Conference* (2001), pages 17-33. Available at http://gulliver.trb.org/publications/conf/reports/cp_26.pdf.

Poister, T.H., Margolis, D.L., and Zimmerman, D.E. Strategic Management at the Pennsylvania Department of Transportation: A Results-Driven Approach (2004). *Transportation Research Record* (1885), pages 56-64.

Poister, T.H. *NCHRP Synthesis of Highway Practice 238: Performance Measurement in State Departments of Transportation.* Transportation Research Board, Washington, D.C., 1997.

Poister, T.H. *NCHRP Synthesis 326: Strategic Planning and Decision-Making in State Departments of Transportation.* Transportation Research Board, Washington, D.C., 2004.

Poister, T.H. Performance Measurement in Transportation: State of the Practice. Report of a Conference, Irvine, California, August 22-24, 2004. *Second National Conference on Performance Measures (*36) (2005), pages 81-98. Available at http://onlinepubs.trb.org/onlinepubs/conf/CP36.pdf.

Poister, T.H., and Van Slyke, D.M. *NCHRP Web Document 39: Managing Change in State Departments of Transportation. Scan 1 of 8: Innovations in Strategic Leadership and Measurement for State DOTS.* National Cooperative Highway Research Program, Georgia State University, 2001.

Shaw, T. *NCHRP Synthesis 311: Performance Measures of Operational Effectiveness for Highway Segments and Systems.* Transportation Research Board, 2003.

TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System. Transportation Research Board; Kittelson and Associates, Inc., 2003.

TransTech Management, Inc. *Strategic Performance Measures for State Departments of Transportation: A Handbook for CEOs and Executives.* TransTech Management, Inc.; American Association of State Highway and Transportation Officials, Washington, D.C., 2003.

TransTech Management, Inc. *Measuring Performance Among State DOTs.* American Association of State Highway and Transportation Officials; Federal Highway Administration; Washington, D.C., 2006.

Transportation System Monitoring and Enhancement

Adams, L.H., Harrison, F.D., and Vandervalk, A. Issues and Challenges in Using Existing Data and Tools for Performance Measurement. Report of a Conference, Irvine, California, August 22-24, 2004. *Second National Conference on Performance Measures (*36) (2005), pages 131-140. Available at http://onlinepubs.trb.org/onlinepubs/conf/CP36.pdf.

American Planning Association. Land-Based Classification Standards: www.planning.org/lbcs/.

Bahar, G., Masliah, M., Mollett, C., and Persaud, B. *NCHRP Report 501: Integrated Safety Management Process.* Transportation Research Board; iTRANS Consulting, Inc., Washington, D.C., 2003.

Bhat, C.R., Bricka, S., La Mondia, J., Kapur, A., Guo, J.Y., and Sen, S. *Metropolitan Area Transit Accessibility Analysis Tool.* Report No. 0-5178-P3). Texas University; Texas Department of Transportation, Austin, Texas, 2006.

Brydia, R.E., Schneider IV, W.H., Mattingly, S.P., Sattler, M.L., and Upayokin, A. *Operations-Oriented Performance Measures for Freeway Management Systems: Year 1 Report* No. FHWA/TX-07/0-5292-1). Texas Transportation Institute; Texas Department of Transportation; Federal Highway Administration, Austin, Texas, 2007.

Cambridge Systematics, Inc. *NCHRP Report 446: A Guidebook for Performance-Based Transportation Planning.* Transportation Research Board; Cambridge Systematics, Inc., Washington, D.C., 2000.

Cambridge Systematics, Inc. *NCHRP 7-15, Task 1.3: Cost-Effective Measures and Planning Procedures for Travel Time, Delay, and Reliability.* Transportation Research Board, Washington, D.C., 2005.

Cambridge Systematics, Inc. *NCHRP Research Results Digest 312: Guide to Effective Freeway Performance Measurement.* Transportation Research Board, Washington, D.C., 2007.

Chen, C., Li, W., and Kwan, M. Point-Based Accessibility and Individual-Based Accessibility. *Transportation Research Board 86th Annual Meeting.* 18 pages. Transportation Research Board, Washington, D.C., 2007.

Donaldson, B.M., and Weber, J.T. *Use of a GIS-Based Model of Habitat Cores and Landscape Corridors for the Virginia Department of Transportation's Project Planning and Environmental Scoping.* Virginia Transportation Research Council; Virginia Department of Transportation; Federal Highway Administration, 2006.

El-Geneidy, A.M., and Levinson, D.M. *Access to Destinations: Development of Accessibility Measures.* University of Minnesota, Minneapolis; Minnesota Department of Transportation, Minneapolis, Minnesota, 2006.

Federal Geographic Data Committee: www.fgdc.gov/metadata/geospatial-metadata-standards.

Harrison, R., Schofield, M., Loftus-Otway, L., Middleton, D., and West, J. *Developing Freight Highway Corridor Performance Measure Strategies in Texas* No. FHWA/TX-07/0-5410-1). Texas University, Austin; Texas Department of Transportation; Federal Highway Administration, Austin, Texas, 2006.

Hendren and Meyers. *NCHRP Project 08-36, Task 53 (02): Peer Exchange Series on State and Metropolitan Transportation Planning Issues. Meeting 2: Non-Traditional Performance Measures.* Transportation Research Board, Washington, D.C., 2006.

Levinson, D.M., and Krizek, K.J. *Access to Destinations.* Elsevier, 2005.

MacDonald, D., Yew, C.P., Arnold, R., Baxter, J., Halvorson, R.K., Kassoff, H. et al. *Transportation Performance Measures in Australia, Canada, Japan, and New Zealand.* American Trade Initiatives; Federal Highway Administration; American Association of State Highway and Transportation Officials, Washington, D.C., 2004.

Meyer, M. Measuring That Which Cannot Be Measured – At Least According to Conventional Wisdom. Report of a Conference, Irvine, California, October 29-November 1, 2000. *Performance Measures to Improve Transportation Systems and Agency Operations* (2001). Pages 105-125. Available at http://www.trb.org/publications/conf/reports/cp_26.pdf.

Muller, B., Johnson, L.E., Wyckoff, J.W., Nuszdorfer, F., and Beckham, B. Areawide Cumulative Effects Analysis Using GIS. *Transportation Research Board 86th Annual Meeting.* 18 pages. Transportation Research Board, Washington, D.C., 2007.

National Biological Information Infrastructure. www.nbii.gov/portal/server.pt.

National Information Exchange Model. www.neim.gov/index.php.

Randall, J.E. (Forthcoming, 2007). *NCHRP 03-81: Strategies for Integrated Operation of Freeway and Arterial Corridors.* Transportation Research Board, Washington, D.C.

Shaw, T. *NCHRP Synthesis 311: Performance Measures of Operational Effectiveness for Highway Segments and Systems.* Transportation Research Board, Washington, D.C., 2003.

Environmental Stewardship

American Association of State Highway and Transportation Officials (AASHTO). *AASHTO Center for Environmental Excellence* (2007). Available at http://environment.transportation.org/. Last accessed on August 3, 2007.

Amekudzi, A., and Meyer, M.D. *NCHRP Report 541: Consideration of Environmental Factors in Transportation Systems Planning.* Transportation Research Board, 2005.

Bracaglia, F. *NCHRP Web Document 79: Monitoring, Analyzing, and Reporting on the Environmental Streamlining Pilot Projects.* Transportation Research Board, Washington, D.C., 2005.

Brown, J.W. *Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects.* Volpe National Transportation Systems Center, Federal Highway Administration, 2006.

Cambridge Systematics, Inc. (forthcoming). *NCHRP Project 25-25, Task 23: Guidelines for Environmental Performance Measurements.* Transportation Research Board, Washington, D.C.

Cambridge Systematics, Inc., Parsons Brinckerhoff, and Venner Consulting, Inc. *NCHRP Web Only Document 103: Final Report for NCHRP Research Results Digest 317: Prototype Software for an Environmental Information Management and Decision Support System.* Transportation Research Board, Washington, D.C., 2006.

Center for Sustainable Transportation (CST). *Sustainable Transportation Performance Indicators Project.* University of Winnipeg, Winnipeg, Manitoba, 2001.

DOT-Funded Positions and Other Support to Resource and Regulatory Agencies, Tribes, and Non-Governmental Organizations for Environmental Stewardship and Streamlining Initiatives. (2005). Retrieved July 12, 2007. Available at http://environment.transportation.org/center/products_programs/dot_funded.aspx.

Environmental plan: improving environmental sustainability and public health in New Zealand (2004). Transit New Zealand. Wellington, New Zealand.

Environmental Stewardship and Transportation Infrastructure Project Reviews: Executive Order Implementation. U.S. Department of

Transportation, Washington, D.C. Last updated December 2006. Available at http://www.dot.gov/execorder/13274/index.htm. Referenced on July 12, 2007.

Environmental Research Needs in Transportation: Report of a Conference, Washington, D.C., March 21-23, 2002. (2002). Washington, D.C. Page 268. Available At http://trb.org/publications/conf/reports/cp_28.pdf.

Evink, G.L. *NCHRP Synthesis 305: Interaction Between Roadways and Wildlife Ecology*. Transportation Research Board, 2002.

FHWA (1999), *The Environmental Guidebook,* Federal Highway Administration, FHWA-99-005. Last updated 2007. Available at www.fhwa.dot.gov/environment/guidebook/index.htm. Referenced on July 12, 2007.

FHWA Office of Planning, Environment, & Realty (2007). *Environmental Review Toolkit, Streamlining and Stewardship.* Last updated July 2007. Available at http://environment.fhwa.dot.gov/strmlng/index.asp. Referenced on July 12, 2007. Washington, D.C.

The Gallup Organization. *Implementing Performance Measurement in Environmental Streamlining,* prepared for U.S. Federal Highway Administration, Washington, D.C., 2004.

The Green Highways Initiative: http://www.greenhighways.org.

Litman, T. *Well Measured – Developing Indicators for Comprehensive and Sustainable Transport Planning.* Victoria, BC: Victoria Transport Policy Institute, Canada, 2005.

The Louis Berger Group, Inc. *NCHRP Report 466: Desk Reference for Estimating the Indirect Effects of Proposed Transportation Projects.* Transportation Research Board, Washington, D.C., 2002.

Measures, Markers, and Mileposts: The Gray Notebook for the Quarter Ending March 31, 2007. Washington State Department of Transportation, Olympia, Washington, 2007.

Paving the Way to Cleaner, Greener Highways, the Mid-Atlantic Green Highways Initiative, January 2006.

Schwartz, M. Technologies to Improve Consideration of Environmental Concerns in Transportation Decisions. *NCHRP Research Results Digest (*304), page 37, 2006.

State DOT Environmental Programs: Evaluation and Performance Measures. Wisconsin Department of Transportation, Research, Development, and Technology Transfer, Madison, Wisconsin, 2007.

Sustainable Development Strategy, 2007-2009 (2006). No. TP 13123. Ottawa, Ontario: Transport Canada. Available at http://www.tc.gc.ca/programs/environment/SD/sds0709/menu.htm. Accessed on July 12, 2007.

TERM 2001: Indicators Tracking Transport and Environment Integration in the European Union: Summary. European Environment Agency, Copenhagen, Denmark, 2001.

Thieman, S. Strategic Transportation, Environmental Planning Process for Urbanizing Places (STEP UP). *10th National Conference on Transportation Planning for Small- and Medium-Sized Communities.* Page 11, Transportation Research Board, Washington, D.C., 2006.

Venner, M. Managing Environmental Performance at State Transportation Agencies. *Transportation Research Record (*1859), pages 9-18, 2003.

Venner, M. *NCHRP Project 25-25, Task 10: Early Mitigation for Net Environmental Benefit: Meaningful Off-Setting Measures for Unavoidable Impacts.* Transportation Research Board, Washington, D.C., 2005.

Virginia Geographic Information Network (VGIN) (2007). Virginia Geographic Information Network. Last accessed on August 13, 2007. Accessible at http://www.vgin.state.va.us/.

Wisconsin Land Information Clearinghouse (WiscLINC) (2007). Wisconsin Land Information Clearinghouse. Last accessed on August 13, 2007. Accessible at http://www.sco.wisc.edu/wisclinc/.

Community Enhancement

American Association of State Highway and Transportation Officials (AASHTO). *A Guide for Achieving Flexibility in Highway Design.* Washington, D.C., 2004.

Cambridge Systematics, Inc. *NCHRP 08-36, Task 11: Technical Methods to Support Analysis of Environmental-Justice Issues.* Transportation Research Board, Washington, D.C., 2002.

Cambridge Systematics, Inc. *NCHRP 08-36, Task 12A: Analysis of the Factors Affecting Future Transportation Environment and their Implications for State DOTs.* Transportation Research Board, Washington, D.C., 2002.

Cambridge Systematics, Inc. *NCHRP 08-36, Task 22: Demonstrating the Positive Impacts of Transportation Investments on Economic, Social, Environmental, Community, and Quality of Life Issues.* Transportation Research Board, Washington, D.C., 2002.

Cambridge Systematics, Inc. *Transportation Impacts of Smart Growth and Comprehensive Planning Initiatives.* Prepared for American Association of State Highway and Transportation Officials and Federal Highway Administration through National Cooperative Highway Research Program Project 25-25(02), 2004.

Cervero, R., Murphy, S., Ferrell, C., Goguts, N., Tsai, Y.H., Arrington, G.B. et al. *TCRP Report 102: Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects.* Transportation Research Board, Washington, D.C., 2004.

Edwards, M.R., Peer, R.L., Lindner, E., and Klein, T.H. *NCHRP Report 542: Evaluating Cultural Resource Significance: Implementation Tools.* Transportation Research Board, URS Group, Inc., Washington, D.C., 2005.

Flexibility in Highway Design. Washington, D.C.: Federal Highway Administration, 1997.

Forkenbrock, D.J., and Sheeley, J. *NCHRP Report 532: Effective Methods for Environmental Justice Assessment.* Transportation Research Board, University of Iowa, Iowa City; Washington, D.C., 2004.

Forkenbrock, D.J., and Weisbrod, G.E. *NCHRP Report 456: Guidebook for Assessing the Social and Economic Effects of Transportation Projects.* Transportation Research Board; University of Iowa, Iowa City, 2001.

ICF Consulting. *Handbook on Integrating Land Use Considerations into Transportation Projects to Address Induced Growth* No. NCHRP 25-25/Task 03). Transportation Research Board, Washington, D.C., 2005.

NCHRP Report 423A: Land Use Impacts of Transportation: A Guidebook. Transportation Research Board; Parsons, Brinckerhoff, Quade and Douglas, Inc., Washington, D.C., 1999.

Neuman, T.R., Schwartz, M., Clark, L., Bednar, J., Forbes, D., Vomacka, D. et al., (2002). *NCHRP Report 480: A Guide to Best Practices for Achieving Context Sensitive Solutions.* Transportation Research Board; EDAW, Inc., Washington, D.C., 2002.

The Louis Berger Group, Inc. *NCHRP Report 466: Desk Reference for Estimating the Indirect Effects of Proposed Transportation Projects.* Transportation Research Board, Washington, D.C., 2002.

Thinking Beyond the Pavement. *AASHTO Quarterly Magazine, 77*(3). Pages 7-34, 1998.

TransTech Management, Inc. *NCHRP Web Document 69: Performance Measures for Context Sensitive Solutions – A Guidebook for State DOTs* (2004). Washington, D.C.: National Cooperative Highway Research Program. July 15, 2007, Available at http://trb.org/publications/nchrp/nchrp_w69.pdf.

Ward, B.G. *Measuring the Effectiveness of Community Impact Assessment: Recommended Core Measures* No. FDOT BC353-28). University of South Florida, Tampa; Florida Department of Transportation; Federal Highway Administration, Tallahassee, Florida, 2005.

Economic Impact and Development

Babcock, M.W. *Approximation of the Economic Impacts of the Kansas Comprehensive Transportation Program.* Kansas State University, Manhattan; Kansas Department of Transportation, Topeka, Kansas, 2004.

Cambridge Systematics, Inc. *NCHRP 08-36, Task 12A: Analysis of the Factors Affecting Future Transportation Environment and their Implications for State DOTs.* Transportation Research Board, Washington, D.C., 2002.

Cox, W. Maximizing Urban Transport Economic Benefits: Urban Performance Indicators. *Competition and Ownership in Land Passenger Transport. 9th International Conference (Thredbo 9)*. Pages 231-246, 2007.

Economic Analysis Primer. Federal Highway Administration. Washington, D.C., 2003.

Economic Development Research Group, Inc. *Monetary Valuation per Dollar of Investment in Different Performance Measures.* Prepared for National Cooperative Highway Research Program and AASHTO Standing Committee on Planning. Transportation Research Board, Washington, D.C., 2007.

Highway and Transit Investments: Options for Improving Information on Projects' Benefits and Costs and Increasing Accountability for Results. No. GAO-05-172. U.S. Government Accountability Office, Washington, D.C., 2005.

Lakshmanan, T.R., and Chatterjee, L.R. Economic Consequences of Transport Improvements. *Access (*26). Pages 28-33, 2005.

Lewis, D. *NCHRP Report 342: Primer on Transportation, Productivity and Economic Development.* Transportation Research Board, Washington, D.C., 1991.

A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements, 1977. American Association of State Highway and Transportation Officials, Washington, D.C., 1978.

Pickton, T., Clements, J., and Felsburg, R.W. *Statewide Economic Benefits of Transportation Investment.* BBC Research & Consulting; Felsburg Holt & Ullevig; Colorado Department of Transportation; Federal Highway Administration, Denver, Colorado, 2007.

Rose, D.C., Gluck, J., Williams, K., and Kramer, J. *NCHRP Report 548: A Guidebook for Including Access Management in Transportation Planning.* Transportation Research Board, Washington, D.C., 2005.

Roskin, M. (2003). Transportation and Economic Development 2002. *Transportation and Economic Development 2002 Conference,* Portland Oregon. 104 pages. Available at http://gulliver.trb.org/publications/circulars/ec050.pdf. Transportation Research Board.

Weisbrod, G., Vary, D., and Treyz, G. *NCHRP Report 463: Economic Implications of Congestion.* Transportation Research Board; Cambridge Systematics, Inc., 2001.

Weisbrod, G., and Weisbrod, B. (1997). Assessing the Economic Impact of Transportation Projects: How to Choose the Appropriate Technique for Your Project. Transportation Research Circular (477). Page 28, 1997.

APPENDIX A

Case Studies

Web Tool Case Studies

The supporting case studies included in the web tool are listed in Table A.1, organized by agency. Additional descriptions and links to the agencies will be available on the web tool when it is released.

Partnership for Integrated Planning

The Partnership for Integrated Planning was a pilot program in California launched in 2001 through collaboration between the Merced County Association of Governments (MCAG), USEPA, FHWA, and Caltrans. The partnership was formed to utilize an alternative process in the development of MCAG's 2004 Regional Transportation Plan (RTP) update. The new process focused on environmental concerns and the inclusion of the public using a number of strategies, including:

- Incorporating environmental concerns into the RTP update;
- Conducting an Environmental Impact Report for the RTP;
- Streamlining the project delivery process; and
- Using GIS tools to model land use with transportation projects and environmental data layers.

This focus meant that the 2004 RTP update differed from the traditional long-range planning process in a number of ways. First, using GIS and modeling tools allowed MCAG to explore the cumulative impacts analysis of land use and transportation decisions within the RTP's 26-year horizon, and on a regional scale. Bringing the land use, transportation, and environmental data layers together required cooperation among agencies that had not collaborated previously. Second, the analysis tools provided a picture of how a selected group of projects will collectively impact habitats, wetlands, and prime agricultural land. Third, the final version of the RTP allowed enough flexibility so that transportation projects could be modified in the planning stage if significant cumulative impacts were identified later. As specific projects are programmed, the regional assessment can provide the overall context and impact analysis. Finally, this RTP process was designed to increase the public participation significantly. The scenario planning and visual representation provided an engaging tool for use in gathering public comment and ideas.

Using the PIP process, MCAG developed five development scenarios: Current Policy, Some Changes, More Changes, Alternative Modes, and Alternative Modes and Roads *(1)*.

Each scenario was evaluated using the measures in Table A.2.

Combined, the analysis of these measures helped MCAG select the preferred alternative for the RTP, which was unanimously adopted by the agency's governing board.

Cumulative Impacts

As part of the PIP process, a Cumulative Impacts Panel was established. The panel's purpose was to develop guidelines and a methodology for identifying mitigation responsibility and strategies for the anticipated impacts at the scenario planning stages during the RTP development process. Since these activities have typically been conducted at the project level during the environmental review process, this differed significantly from the standard approach. The cumulative impacts of each scenario were compared to a no-plan alternative in five areas: agriculture (acres), wetland (acres), potential habitat (acres), cultural (acres), historic sites (number of sites).

Tools

MCAG utilized two tools to evaluate the effects of new facilities on land use, and the subsequent impact on habitats and environmentally sensitive areas:

- **UPlan –** a scenario-based GIS modeling tool. This model can project land development patterns based on a set of

(text continues on page 79)

Agency Name	Case Study Name	Mobility	Reliability	Accessibility	Safety	Water Quality	Ecosystem, biodiversity, habitat	Wetlands	Air Quality	Environmental Health	Climate Change	Economic Impact	Economic Development	Land Use	Historic, cultural, archeological	Social	Environmental Justice	Cost	Cost Effective
American Lung Association of Sacramento-Emigrant Trails Health Effects Task Force	Sacramento/?Interstate-5 Aerosol Transect Study Winter Months 2003-2005								X	X				X					
Arizona DOT	Comprehensive Approach to Wildlife Protection on State Route 260				X		X												
Arizona DOT	Arizona's Wildlife Linkages Assessment				X		X												
Arizona DOT	ADOT MoveAZ Transportation Plan	X	X		X														
Atlanta Regional Commission	Atlanta Regional Commission Envision6 RTP, FY 08-13 TIP	X	X	X		X		X						X	X				
Breathe California of Sacramento-Emigrant Trails	Vehicular Exposures and Potential Mitigations Downwind of Watt Avenue, Sacramento, CA								X	X									
California Department of Transportation	Transportation Project-Level Carbon Monoxide Protocol (CO Protocol)								X										
California Department of Transportation (Caltrans) and UC Davis Institute of Transportation Studies	Estimating Mobile Source Air Toxics Emissions: A Step-By-Step Project Analysis Methodology								X										
California Department of Transportation (Caltrans) and UC Davis Institute of Transportation Studies	EMFAC Model for Air Toxics								X										

California Department of Transportation (Caltrans) and UC Davis Institute of Transportation Studies	Proposed State Route 125 South Air Emissions and the Sweetwater Reservoir: A Review of Recent Reports Sponsored by the Sweetwater Authority					X			X										
Capital District Transportation Committee	Albany, NY – New Visions 2030 (Regional Transportation Plan)													X					
Capital District Transportation Committee	Albany, NY Congestion Management Process			X	X		X		X			X		X					
Colorado DOT	Colorado I-70 Mountain Corridor Tier 1 EIS					X	X	X	X			X	X	X	X	X			
Colorado DOT, FHWA, The Nature Conservancy, Colorado State University through the Southern Rockies Ecosystem Project	Linking Colorado's Land-scapes and the Southern Rockies Ecosystem Project				X		X												
Denver Regional Council of Governments	DRCOG FY 08-13 TIP	X	X		X									X					X
EPA	National Air Toxics Assessment (NATA)								X										
EPA	EPA Storm Water Management Model (SWMM)					X	X	X											
EPA	National Air Toxics Trends Stations (NATTS)								X										
EPA	EPA EnviroMapper for Water					X	X	X											
EPA	EPA MOBILE model and Motor Vehicle Emissions Simulator (MOVES)										X								
EPA	EPA WATERS Expert Query Tool					X													
EPA; FHWA; Maryland State Highway Administration	Green Highways Partnership					X	X	X											

Table A.1. SHRP 2 C02 Performance Measures Case Studies

(continued on next page)

Agency Name	Case Study Name	Mobility	Reliability	Accessibility	Safety	Water Quality	Ecosystem, biodiversity, habitat	Wetlands	Air Quality	Environmental Health	Climate Change	Economic Impact	Economic Development	Land Use	Historic, cultural, archeological	Social	Environmental Justice	Cost	Cost Effective
FHWA, Nevada DOT	U.S. 95 in Nevada: Transportation-Related Air Toxics								X										
Florida DOT	Florida's Wildlife Species Ranking Process						X												
Florida DOT	Environmental Screening Tool					X	X	X						X	X	X			
Florida DOT	Strategic Intermodal System Plan	X		X	X	X	X	X				X	X		X	X			
Florida DOT	Florida's Sociocultural Effects Evaluation	X			X							X	X	X	X	X			
Indiana DOT	Indiana Planning Oversight Committee																		X
Low-Impact Development Center	Low-Impact Development Urban Design Tools					X													
Maryland State Highway Association	Green Highway U.S. Route 301					X	X	X	X		X			X					
Merced County Association of Governments	Partnership for Integrated Planning						X	X	X					X					
Metropolitan Transportation Commission	San Francisco Bay Area Regional Transportation Plan – Equity Analysis			X												X	X		
Mid-Ohio Regional Planning Commission	Columbus, Ohio Regional Transportation Plan – EJ Analysis			X												X	X		
Ministry of Transport, Public Works, and Water Management	Citizens Value Assessment															X			
Minnesota DOT	Mn/Model														X				

Minnesota DOT	MnDOT 2003 Statewide Transportation Plan	X	X	X	X	X	X		X					X					
Minnesota DOT	MnDOT Metro Area Ramp Meter Study		X		X														
Montana Department of Transportation	Wildlife Vehicle Collision and Crossing Mitigation Measures: A Toolbox for the Montana Department of Transportation				X		X												
National Oceanic and Atmospheric Administration	Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT)					X	X	X						X					
National Oceanic and Atmospheric Administration; University of Connecticut	Impervious Surface Analysis Tool					X	X	X											
New Hampshire Fish and Game Department	New Hampshire Wildlife Action Plan						X												
North Carolina DOT and North Carolina Department of Environment and Natural Resources (NCDENR)	North Carolina Ecosystem Enhancement Program					X	X	X											
North Carolina DOT	Highway 311 Corridor Study							X											
Oregon DOT	Collaborative Environmental and Transportation Agreement on Streamlining (CETAS)					X	X	X											
Pennsylvania DOT	PennDOT Cultural Resources GIS														X				
Puget Sound Regional Council	Seattle – Destination 2030 and Vision 2040	X	X	X		X	X		X		X		X	X					
South Coast Air Quality Management District	Multiple Air Toxics Exposure Study (MATES-II)								X										
Southern California Association of Governments	SCAG Long-Range Transportation Plan																X		
Tahoe Regional Planning Agency (TRPA)	TRPA Scenic Shoreline Assessment System (SSAS)															X			

Table A.1. (Continued).

(continued on next page)

Table A.1. (Continued).

Agency Name	Case Study Name	Mobility	Reliability	Accessibility	Safety	Water Quality	Ecosystem, biodiversity, habitat	Wetlands	Air Quality	Environmental Health	Climate Change	Economic Impact	Economic Development	Land Use	Historic, cultural, archeological	Social	Environmental Justice	Cost	Cost Effective
USGS	USGS National Hydrography Dataset					X	X	X											
Washington State DOT	Transportation Project Mitigation Cost Screening Matrix					X	X	X						X	X			X	
Washington State DOT	Interstate 405 Corridor Remote Sensing Study						X	X											
Washington State DOT	WSDOT Reliability Measures	X	X																
World Resources Institute	Climate Analysis Indicators Tool										X								

Factor Area	Measurement	Unit	High or Low?
Mobility	Lane-miles of congestion in 2030	Lane-miles	Lower is better
Accessibility	Transit ridership in 2030	Millions riders/year	Higher is better
	Funding for bike paths and sidewalks	Millions of dollars	Higher is better
Safety	Accidents reduced in the next 25 years	Accidents	Higher is better
Air Quality	Emissions (pollution) in 2030	Tons per day	Lower is better
Land Use	Land Converted to urban uses	Square miles	Lower is better
	Acres of farmlands directly impacted	Acres	Lower is better
Cost	Environmental Mitigation Cost	Millions of dollars	Lower is better
	Total regional cost per scenario	Millions of dollars	Lower is better

Source: *http://www.mcagov.org/?PROJECTS/?TRANS/?1460.htm*

Table A.2. MCAG Scenario Evaluation Measures

assumptions about densities, environmental constraints, and local land use plans. The program enabled PIP participants and stakeholders to understand the implications of different plans and evaluated scenarios. This tool can be used at the city, county, or watershed scale *(2)*.

- **HePlan** – a habitat evaluation and planning model that predicts the occurrence of habitat areas based on environmental data layers. This tool allows users to scale conservation preferences or goals based on potentially affected habitats. Like UPlan, it can be used at city, county, or watershed scale.

MCAG identified some significant accomplishments as a result of the PIP process. From the partnership and collaboration perspective, they found that this process provided a good platform for establishing a new level of mutual understanding with the relevant resource agencies about regulations, policies, and cumulative impact analysis. This served to achieve a more thorough analysis of environmental impacts. The process also initiated the effort to begin compiling environmental data layers into a format usable for all partners. The process lent itself well to public participation, and MCAG noted that it resulted in a 30 percent increase in the number of county residents aware of the RTP process. Finally, the RTP was unanimously approved by the MCAG governing board on the first round.

Atlanta Regional Commission Envision6/ FY 08-13 TIP Project Evaluation System Expansion Projects

For the latest update to the long-range transportation plan (LRTP) and short-range transportation improvement program (TIP), referred to as Envision6, the Atlanta Regional Commission (ARC) staff developed and implemented a detailed project prioritization methodology to evaluate *system expansion projects* (Transit Capital, Roadway Capacity, and HOV Lanes) that incorporated the Georgia Governor's Congestion Mitigation Task Force and ARC Board recommendation to increase weighting of congestion reduction in project selection to 70 percent. ARC staff prepared a technical framework to accommodate this recommendation, while also respecting additional Board guidance to develop a project selection process that is consistent with Envision6 development and growth policies and the Regional Strategic Transportation System (RSTS – a roadway system of predefined facilities eligible to receive federal transportation funding).

All system expansion projects were first screened against the RSTS. Those capacity-adding projects that fell on the RSTS were evaluated using a technical analysis to quantify how well each project performs in relation to four evaluation criteria defined below. The technical analysis was not used to provide an assessment of the type of treatment needed for a facility. It was an evaluation used to compare existing project proposals relative to one another to aid in project selection. Projects received up to 100 points based on an assessment of:

- **Recurring delay,** which occurs as routine traffic volume exceeds available roadway capacity;
- **Nonrecurring (incident) delay,** which occurs as a result of traffic incidents;
- **Environmental impact,** which measures a project's proximity to six environmentally sensitive areas; and
- **Regional Development Plan (RDP) policy support,** which measures how well a project supports ARC's growth policies based on project location and scope.

A benefit/cost calculation was used to determine the project's placement within different years of the TIP and LRTP. Project benefits reflect the dollar value of time-travel savings (delay reduction) for commercial vehicle and person time as well as fuel-cost savings. Project costs reflect funding allocations for preliminary engineering, R/W, and construction.

Evaluation Process

Recurring Congestion (50 points). Points were awarded based on the level of (recurring) delay reduction each project provides. For roadway capacity-adding projects (to include HOV lane projects), points were allocated based on how well each project scored in relation to three congestion metrics – intensity, duration, and extent. A travel demand model post-processor was used to compare network performance of the 2030 Build scenario to a 2030 No-Build scenario, in terms of each project's impact on the intensity, duration, and extent of congestion.

- **Congestion Intensity –** Total delay the project corridor experiences during the most congested period of the day.
- **Congestion Duration –** Average total hours during the day that a facility exhibits congested conditions.
- **Congestion Extent –** Total daily delay experienced by all vehicles using the project corridor.

For transit capacity projects, recurring delay benefits were estimated using FTA's SUMMIT software. The SUMMIT software produces several outputs, including but not limited to: number of person and transit trips for a no-build scenario; change in person and transit trips resulting from the Build scenario; and the transportation system User Benefit Hours that result from the Build scenario. The absolute value of each project's User Benefit Hours total was translated to a final score ranging from 0 to 50.

Nonrecurring Congestion (20 points). For roadway capacity projects, points were awarded based on a comparison of the project crash rate at a particular road segment (the segment within a project's limits) to a regionwide crash rate on roadways of similar functional classification. Projects that exceeded the regional crash rate average by the most were awarded the most points, up to 20 points. Crash data used in the analysis was extracted from the statewide Georgia CARE crash database. Crash rates were calculated for a five-year average, 2000-2004.

To determine the impact of transit projects on incident-based roadway congestion, an original formula was devised to estimate the number of crashes prevented from occurring on the roadway system as the result of a specific transit investment. This effective reduction in crashes, which in turn leads to a commensurate reduction in incident-based congestion, was used as an indicator of how well the transit project mitigates nonrecurring roadway congestion resulting from crashes. Points were awarded by calculating the difference between the respective crash rates for private vehicle travel and the transit technology for a particular project, and then applying this difference to the passenger mileage for the project in question. Transit crash rates by transit technology (e.g., BRT, heavy-rail, light-rail) were acquired from national and local statistics. Private vehicle crash rates were acquired from the Georgia CARE crash database.

Environmental Impact (15 points). For both roadway capacity and transit capacity projects, points were assigned based on each project's geographic proximity to six environmentally sensitive areas: Historic Resources, Wetlands, Floodplains, Parks, Water Bodies, and Small Area Supply Watersheds. This was done using a raster-based (grid-based) GIS analysis that applies more points with greater cumulative environmental impact. Transportation capacity projects were mapped to the environmental areas and the cumulative environmental impact was calculated based on the number and type of sensitive areas that the project impacts (i.e., touches). Points were assigned based on the aggregate environmental impact and then inverted to avoid rewarding projects (i.e., higher score) with greater environmental impact. This work was done in ESRI's ArcGIS desktop software with the Spatial Analyst extension.

Growth Policy Support (15 points): For both roadway and transit capacity projects, points were awarded based on each project's ability to support "place-based" transportation objectives, as defined by the appropriate land use place type (e.g., CBD, suburban neighborhood, rural area, etc.). Place-based transportation objectives were developed through ARC staff and planning partner discussions on transportation elements that should be included as part of a project's scope to support regional development growth policies. Examples of these elements used for scoring included: transit amenities, bike/pedestrian amenities, ITS elements, demand management elements, and connectivity between centers, context-sensitive elements, and local land use commitment. Points were assigned based on the number and type of objectives that were met as part of the project proposal. A unique distribution of points was determined for each of the eight land use place types, with the various objectives weighted differently based on their relative importance in the context of the specific place type. All projects were first mapped to the ARC Unified Growth Policy Map to define the appropriate land use place type. Up to 15 points were then assigned based on the number and type of transportation objectives that each project supported.

Total Project Scores (100 points): Total project scores were calculated by summing points over each of the four evaluation criteria. Total scores were used to place projects into one of three tiers with Tier 1 representing the top third (best performing projects), Tier 2 representing the middle third of projects (average overall score), and Tier 3 the bottom third (worst performing projects). Tier rankings were used as the primary criteria for determining which projects were ultimately selected for funding.

California Benefit/Cost for Project Evaluation

The California Department of Transportation (Caltrans) currently uses economic analyses to evaluate and prioritize the state's investments to assess which provide the most benefits. One such tool is the California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C). Caltrans has been using Cal-B/C for more than 10 years for a variety of evaluation efforts, some ongoing, and some one-time activities. These include:

- The conduct of investment analyses of improvement projects (highway and transit) proposed for the interregional portion of the State Transportation Improvement Program (STIP);
- Evaluation and programming for projects included in the State Highway Operation and Protection Program; and
- Evaluation of projects for a $4.5 billion bond measure, the Corridor Mobility Improvement Account.

Cal-B/C measures four primary categories of benefits:

- Travel-time savings;
- Vehicle operating costs;
- Safety benefits (accident cost savings); and
- Emission reductions.

Evaluation Process

Cal-B/C is a Microsoft Excel spreadsheet tool that provides economic benefit and cost analyses for the evaluation of a range of capacity-expansion transportation projects. It can be used to compare similar types of projects, prioritize or rank projects, allocate resources, and test project phasing. Cal-B/C is capable of analyzing:

- Highway Capacity Expansion:
  - Lane additions, HOV lanes, passing/truck climbing lanes; and
  - Interchanges, bypasses.
- Transit Capacity Expansion:
  - Passenger rail, light rail, bus projects.
- Operational Improvements:
  - Auxiliary lanes, freeway and HOV connectors; and
  - Off- and on-ramp widening.
- Transportation Management Systems:
  - Ramp metering, signal coordination, incident management; and
  - Traveler information, arterial signal management.

The general methodology used for evaluating each of the performance measures in Cal-B/C are described below. These are obtained directly from the *California Life-Cycle Benefit/Cost Analysis Model (Cal-B/C) – Technical Supplement to User's Guide,* September 1999.

TRAVEL-TIME SAVINGS

The model follows these steps to calculate estimates of annual and 20-year delay savings on highways:

1. Based on the base and future-year ADT projections, the model estimates future annual ADTs, without and with the improvement project, assuming straight-line growth;
2. Annual ADTs are multiplied by the affected length and then divided by the traffic speed to find the total travel time, without and with the improvement project;
3. Annual travel-time savings (the difference between total travel time without and with project) are multiplied by the value of time and average vehicle occupancy for each mode to convert travel-time savings into dollar values; and
4. The dollar values of travel-time savings are discounted to estimate their present value.

Cal-B/C also can accept analysis results from a travel demand model or other traffic analysis models to use as inputs if available.

The process for transit travel-time savings is similar except that annual person trips and total travel time are provided by the user.

VEHICLE OPERATING COSTS (VOC)

The change in highway vehicle operating costs (increased fuel use, vehicle wear and tear, etc. due to improved speed) is estimated as follows:

1. Estimated future annual ADTs are multiplied by the affected segment length to find annual VMT, with and without the project as well as the difference (VMT savings).
2. For each mode, annual VMT savings are multiplied by the fuel consumption (from look-up table based on average speed) and the unit fuel cost to find the dollar value for fuel VOC savings. Annual VMT savings are multiplied by unit nonfuel VOC to find the dollar value of nonfuel VOC savings.
3. Future annual VOC savings are summed across modes and discounted to obtain their present value.

SAFETY BENEFITS (ACCIDENT-COST SAVINGS)

Accident-cost savings on the highway are determined as follows:

1. The aggregated accident cost (per million miles) is calculated by multiplying the accident rate by accident cost for

each type of accident and summing the result. Transit accident-cost savings are calculated similarly, except that the aggregated accident cost is calculated by accident event (i.e., fatality, injury, property damage) rather than accident type.
2. Annual VMT (in million miles) is multiplied by aggregate accident cost (per mile). The result is the annual cost of accidents, without and with the projects.
3. The difference (change in accident cost) is discounted to find the present value of future safety benefits.

Emission Reductions

The values of highway emissions reductions are calculated as follows:

1. The aggregate emissions cost (per mile) is calculated by multiplying the emissions rate by the emissions cost for each type of criteria pollutant and summing the results.
2. Annual VMT (in miles) is multiplied by the aggregate emissions cost. The result is the annual emissions cost, with and without the project.
3. The difference (change in emissions cost) is discounted to find the present value of future emissions benefits.

Value of transit emissions reductions are calculated similarly, except that vehicle-miles (train-miles in the case of passenger trains) are used in place of VMT. Note that the emission rates used in Cal-B/C are based on the California Air Resource Board's (CARB) Emission Factors (EMFAC) model.

Cal-B/C requires relatively few inputs with volume (existing and future) being the main input. The model is set up such that required inputs are colored green (e.g., project type, length of construction period, number of lanes, free flow speed, length, current and forecast ADT volumes, and accident data), red cells represent default values that can be modified by the user (e.g., percent trucks, length of peak-period), and blue cells reflect data items calculated by the model but that can be modified by the user (e.g., with improvement free flow speed and ADT values). Separate sheets are used to enter project costs (project support, right-of-way, construction, maintenance and operations, rehab, mitigation, and agency cost savings) or mode-specific speed and volume inputs from a travel model or other analysis method.

The Cal-B/C model has been made available for other agencies and staff to understand how funding decisions are made and to consider the benefits of their proposed projects. Regional agencies within California have begun to assess the use of Cal-B/C or methods or parameters from Cal-B/C for their Regional Transportation Plan (RTP) project evaluation and prioritization processes. Caltrans recognizes this and has made the Cal-B/C model available for use on their web site *(3)*.

Ontario Ministry of Transportation Life-Cycle Cost Analysis

In order to support development of corridor investment plans, the Ontario Ministry of Transportation developed the Priority Economic Analysis Tool (PEAT) which is used to perform a life-cycle cost analysis of highway and bridge projects. It estimates initial agency costs, future agency costs, and road user costs, including vehicle operation costs, travel-time costs, accident costs, and the cost of delay due to work zones.

The tool is designed to help prioritize competing investment alternatives. PEAT enables agencies to analyze preservation and improvement projects for highways, bridges, and intersections using an economic approach that considers both agency and road user costs. PEAT helps answer two fundamental questions:

1. Is a project a good investment; and
2. If so, when should it be implemented?

The life-cycle cost analysis has been successfully adapted by the Ministry of Transportation of Ontario. It enables the agency to make effective investment decisions based on a full life-cycle cost evaluation, helps agencies justify projects based on objective measures of economic benefit – net present value and benefit/cost ratio, enables the direct comparison of projects involving different asset types (pavements, bridges, and intersections) and different work types (preservation and improvement), and promotes consistent project estimates across an agency.

MTC – Change in Motion

As part of its long-range transportation plan update, Transportation Update 2035 – Change in Motion, the Metropolitan Transportation Commission (MTC) has included greenhouse gas emission reduction as one of its key performance measures for transportation scenario analysis. The MTC serves as the MPO for the Bay Area in California. This area encompasses nine counties with more than seven million people. To aid in the development the new 2035 RTP for the Bay Area, the MTC staff was authorized to proceed with a performance-based approach for assessing investment scenarios relative to specific performance targets. The performance targets are used to help inform policy and investment strategies for the transportation vision. They focus on three principles: Economy, Environment, and Equity.

The MTC scenario analysis was used to test how different system expansion strategies contribute to achieving performance targets. Environmental Performance Targets include the following:

- Carbon dioxide (CO2): 40 percent below 1990 levels. *Source: Governor's Executive Order, S-3-05 (2005)*

- Fine particulate matter ($PM_{2.5}$): 10 percent below 2006 levels.
  Source: State air quality standards
- Coarse particulate matter (PM_{10}): 45 percent below 2006 levels.
  Source: State air quality standards
- VMT per capita: 10 percent below 2006 levels.
  Source: State legislation under consideration in 2007 (SB 375)

Multiple combinations of a land use and pricing policy approach were conducted against several investment scenarios, including:

- **Land Use Sensitivity Analysis –** considerable shifts in regional growth to existing employment and housing centers, areas projected to have either household or employment growth, and areas with existing and/or planned transit.
- **Pricing Sensitivity Analysis –** user-based pricing strategies inducing changes in travel behavior by increasing the cost of driving through a carbon tax or tax on vehicle miles driven, congestion fee for using congested freeways during peak-periods, and increased parking charges for all trips.

Performance measure results and conclusions of the scenario analysis are available on-line. *(4)* The 2035 transportation plan is still under development. Individual project analysis is one of the next steps to occur.

Linking Colorado's Landscapes

Colorado Department of Transportation (CDOT) and the Southern Rockies Ecosystem Project (SREP) is responsible for the Linking Colorado's Landscapes program. This program is designed to identify and prioritize wildlife linkages across the state of Colorado to promote safe passage for wildlife. Habitat fragmentation is one of the greatest threats to biodiversity and the decline of species. This program was initiated in 2003 out of increasing recognition of the impacts that transportation infrastructure has on wildlife movement and an interest in integrating wildlife and environmental considerations into transportation planning and development.

The program is a partnership between Colorado Department of Transportation (CDOT) and the Southern Rockies Ecosystem Project (SREP), and operates in close collaboration with the Federal Highway Administration, The Nature Conservancy, and Colorado State University. The goal of the program is to provide transportation planners, state and federal agencies, community leaders, engineers, and conservationists with a statewide vision for reconnecting habitats that are vital for maintaining healthy populations of native species. In 2006 the FHWA awarded Linking Colorado's Landscapes with their Exemplary Ecosystem Award.

To begin, SREP conducted a study to identify focal species, key habitat areas, and priority environmental connectors. The focus was on identifying large-scale landscape connections that facilitate movements to meet biological requirements for daily, seasonal, or natal dispersal movements for native wildlife across a variety of habitat types and spatial scales.

To achieve the goals of the project, SREP utilized a two-track approach that involved local and regional expertise, as well as computer modeling. The first track engaged experts through a series of interagency workshops held across the state to identify both functioning and degraded wildlife linkages vital to wildlife populations. The workshop participants then evaluated the characteristics and existing condition of each identified linkage.

The second track considered the same questions within the framework of a geographic information system (GIS). This track combined layers of spatial data about landscape characteristics (e.g., topography, rivers, and streams) with wildlife habitat preferences and movement patterns to model areas of the landscape that are important for wildlife movement. The highest priority linkages identified by each of these tracks were then combined with CDOT animal-vehicle collision data and transportation planning data to select a subset of high-priority wildlife linkages for further assessment.

Having identified important wildlife linkages, the next phase of the project was to conduct in-depth analysis for each of these linkages and develop preliminary recommendations for improving highway permeability for wildlife. SREP visited and inventoried each of these linkage areas where they are transected by highways, compiling information on existing structures, and determining how and where animals are traversing from one side of the roadway to the other. These inventory data were combined with other layers of information, such as land ownership and management adjacent to the highway, traffic densities, and zoning. To complete the linkage assessments, SREP partnered with transportation engineers to develop guidelines and recommendations for improving safe passages for wildlife across these critical stretches of highway. These recommendations, combined with information on future highway projects, helped to discern appropriate mitigation measures and funding opportunities.

Measures

Habitat connectivity was the primary landscape attribute of concern, and focal species were chosen to capture the full spectrum of habitat requirements across spatial scales, taxonomic groups, and compositional attributes of wide-ranging species, area-sensitive species, species at-risk, and species reliant on critical resources. Barriers are perceived differently by different species, so species with the most stringent requirements were selected as focal species so that linkage designs would encompass the requirements of species with less stringent requirements as well. The following criteria were considered in selecting focal species:

- Is this species sensitive to habitat fragmentation (i.e., is the species known to be reluctant to traverse barriers, or is it a wide-ranging species for which there are no sufficiently large, intact core habitat patches)?
- Does this species capture the connectivity requirements of other species and/or ecological systems (e.g., ecological niches, behavioral responses to possible barriers)?
- Does the species currently exist in Colorado, or could populations be restored or eventually recolonize an area?
- Is there sufficient knowledge about this species' ecology to assess its connectivity requirements (e.g., home range, dispersal, tolerance to roads or human development/activity, etc.)?
- Does the suite of focal species collectively capture the range of connectivity requirements, habitat associations, and dispersal scales in Colorado?

The project then created and analyzed the overall connectivity of a network of functionally defined resource patches for each focal species. This involved four major steps:

- Define habitat quality. A map of habitat quality was generated that specified the quality of forage resources in terms of 0 (not habitat) to 100 (highest quality habitat). Habitat quality value at a location is a function of the patch vegetation or type of land cover, the proximity of a location to the edge of a patch, and disturbances from nearby land uses and activities (e.g., roads, noise, etc.). Estimates of habitat quality were determined from species-vegetation affinities and based on Colorado GAP *(5)*.
- Define habitat patches by functionally integrating habitat quality with species' ability and need to move among different resources. Functionally defined patches that are "big enough" and "close enough" were defined for a species based on their needs and movement abilities.
- Consider the arrangement or distribution of these functionally defined patches in a landscape to assess interpatch movement and matrix quality. When species move between functionally defined patches they encounter a variety of conditions that may facilitate or inhibit movement. The model explicitly recognizes this "matrix quality" by allowing the specification of permeability values based on land use and cover types.
- Construct a landscape or network that uses the functionally defined patches as graph "nodes" that are connected by graph "edges" that represent the cost-weighted distance between nodes. These networks helped identify "bottlenecks" or "choke points" – locations that are critical for overall connectivity due to the spatial configuration of habitat.

To prioritize across all linkages identified for the full suite of focal species, the study assessed the overall quality, functionality, threat, and conservation opportunity relative to all of the focal species that utilize the linkage. Linkages that scored high for conservation priority, ecological functionality, future threat, and conservation opportunity were ranked as high priority.

The study also conducted roadway site assessments at each of the priority linkage locations. The purpose of these field visits was to collect on-the-ground information to refine the understanding of wildlife current movements through the linkages. These assessments examined:

- **Potential Wildlife Crossing Locales.** Three types of unique situations that could potentially serve as a wildlife crossing locale were identified: 1) structures such as bridges or culverts that can provide a safe passage for wildlife species underneath the roadway; 2) fill slopes where the roadway is elevated relative to the surrounding topography, typically where the roadway bisects a drainage; and 3) at-grade areas identified as potential wildlife crossing locations.
- **Roadway Barriers.** Roadway barriers to wildlife were characterized according to the number of lanes and presence of shoulder barriers, median barriers, and other features. Guard rails were generally not considered as shoulder barriers unless they were present within potential wildlife crossing zones.
- **Focal Zones.** Focal zones are stretches of roadway where wildlife movement was notably concentrated and that offered distinct opportunities for implementing effective mitigation measures to improving highway permeability for wildlife and reducing animal-vehicle collisions.
- **Biological and Site Design Assessments.** Following the roadway inventories and initial compilation of information, CDOT, CDOW, and USFS biologists and engineers jointly visited each priority linkage site. The objectives of these interagency, multidisciplinary site visits were: 1) to bring biological and engineering expertise to locations in the field to discuss potential crossing solutions for wildlife; 2) to brainstorm the range of structural and nonstructural solutions, given the specific considerations at each location (i.e., wildlife needs and constraints, topographical challenges, safety concerns, etc.); and 3) to use these discussions as the basis for developing recommendations for improving highway permeability for wildlife throughout each linkage.

In addition to identifying priority linkages bisected by transportation systems, the study also found that many mitigation measures are not effective (Table A.3).

Mitigation Measure	Concern
Traditional yellow diamond-shaped wildlife crossing signs	Ineffective
Other permanent static wildlife crossing signs	Ineffective
Wildlife reflectors and mirrors	Ineffective
Ultrasonic deer whistles	Ineffective
Culverts and tunnels without associated guide fencing	Ineffective
Warning systems triggered by radio-collared animals	Requires extensive collaring
Animal decoys in ROW	Safety concern
Animal carcasses left in ROW s	Attract scavengers, causing additional AVC
Scent repellents along ROW	May attract some animals
Artificial lighting of roadsides	Some animals avoid lighted areas

Source: Southern Rockies Ecosystem Project, 2006, Linkage Assessment Methodology, Linking Colorado's Landscapes Phase II Report, Southern Rockies Ecosystem Project, Denver, Colorado. http://www.restoretherockies.org/?pdfs/?methodology.pdf

Table A.3. Colorado Evaluation of Mitigation Measures

The report also highlighted mitigation measures that could be more effective. These include:

- Variable message sign;
- Night time speed limit sign;
- Seasonal speed limit sign;
- Wildlife detection system;
- Wildlife fencing;
- Cattle fence setbacks;
- Double cattle guard;
- Escape ramp;
- Ungulate crosswalk;
- Cement box culvert;
- Arch culvert;
- Vegetated overpass;
- Bridge extension; and
- Retaining wall.

Vehicular Exposures and Potential Mitigations Downwind of Watt Avenue, Sacramento, California

Breathe California of Sacramento-Emigrant Trails; The Health Effects Task Force conducted the Watt Avenue case study. There is increasing scientific evidence suggesting that mobile source air toxics are harmful to human health. For more information on the literature addressing exposure and health effects related to mobile source air toxics, see the Health Effects Institute's November 2007 report, *Mobile-Source Air Toxics: A Critical Review of the Literature on Exposure and Health Effects (6)*. Those most at risk for exposure include people at schools, hospitals, nursing homes, and housing units within 300 meters of a major roadway.

To assess the ambient air concentrations of vehicle emissions, the Breathe California Health Effects Task Force sponsored a three-phase study to evaluate vehicular exposures and potential mitigations for atmospheric particulate matter in Sacramento, California. The studies were led by Professor Thomas A. Cahill of the DELTA Group at University of California, Davis. This case study provides an overview of the methodology and major findings, including an assessment of potential mitigation measures that may be relevant for consideration in conjunction with capacity expansion projects in other areas.

A significant finding from the study suggests that very fine and ultrafine toxic particles from cars can be higher on secondary streets than downwind of heavily traveled freeways like I-5 in Sacramento. Also, burning oil in car exhaust may be a more significant health threat than earlier believed.

The first phase of the study measured air pollution levels every three hours at nine sites upwind and downwind of Highway I-5 and east to the foothills. Highway I-5 carries approximately 170,000 vehicles per day, including 10 percent trucks, and is in part a depressed freeway with sound walls and mature large trees between the roadway and downwind receptors. The study found that the level of diesel/smoking gasoline vehicle impacts was larger at a site located downwind of Watt Avenue at the corner of Watt Avenue and Arden way (Arden Middle School), than at a site directly downwind of Highway I-5 (Crocker Art Museum), despite lower traffic flows on Watt Avenue. Very fine particulates traveled well away from freeways and filled large areas of downtown Sacramento.

The second phase examined the impacts from Watt Avenue, a secondary roadway carrying predominantly car traffic with an average of 66,000 vehicles per day. Diesel trucks contributed about one-third of all the very fine and ultrafine particulates, although they represented only about 1.5 percent of the vehicles. Cars contributed two-thirds of the very fine and ultrafine particulates. Particulates from Watt Avenue substantially impacted Arden Middle School.

The third and final phase of the study confirmed the findings from the previous two phases and assessed mitigation options to reduce exposures. Two DELTA 8 DRUM samplers with ultrafine after filters were placed at Arden Middle School. One was placed indoors roughly 12 meters from the right-of-way fence and 15 meters from the nearest road edge; the other was placed outdoors on a roof about 15 meters from the edge of the nearest traffic lane. In addition, the study evaluated two modeling methods – tracer and mass balance. Both the theoretically modeled results and the actual data showed that high levels of vehicular particulate pollution in very fine and ultrafine particulate modes exist directly downwind (east) of Watt Avenue. According to the California Air Resources Board Almanac (2006), these particles are responsible for (at least) 70 percent of all the impact of toxic air contaminants in California, deposit deep into the lung, and possess significant risk to human health.

The data establish that vehicular particulate matter directly downwind of Watt Avenue is at unhealthy levels for subjects that have to bear long-term exposure, even though aerosol mass does not violate any state or federal particulate matter standards. The study identified several factors that exacerbated high exposure levels:

- The expansion of Watt Avenue into a major north-south connector, with an average of 66,000 vehicles per day, typically 1.5 percent trucks;
- The relatively narrow right-of-way;
- The stoplights, including that at Watt Avenue and Arden Way;
- The flat at-grade roadway, without sound walls or major vegetation;
- The lack of barriers between the roadway and downwind areas; and
- The proximity of receptor sites (schools, houses) to the edge of the right-of-way.

Phase 3 of the study also examined four categories of mitigation alternatives which could be valuable for highway capacity planning. Some of these would be applicable only to new development and need additional regulations, while some could be applied on existing roadways:

1. Source reduction on the roadway, including:
   – Repair or eliminate the roughly 10 percent of oil-burning gross emitting cars through enhanced smog checks;
   – Adjust signal timing to reduce vehicle congestion and idling cars;
   – Encourage alternative transportation;
   – Redesign the intersection so that there are no stop lights, materially decreasing the pollution from the stopped and accelerating cars and trucks;
   – Close the road to heavy trucks during school hours. This would provide a modest improvement, as diesels are an established source of toxic air contaminants; and
   – Build a parallel road of improved design that would reduce traffic on Watt Avenue without adding pollution to another site.
2. Roadway design improvements, including:
   – Vehicles on a highway create a mixed zone due to the turbulence of the vehicles, which is roughly 1.5 times the height of the mean vehicle at freeway speeds, less at low speeds. This mixed zone contains emissions from the vehicles, including waste heat, which tends to make the road pollution slightly buoyant. This buoyant lift can be enhanced by placing a barrier to direct lateral motion from the roadway, slowing the lateral velocity and allowing the lift to raise the pollution level and entraining cleaner higher altitude air. Thus, roadways should be designed to hinder easy lateral transport of pollution and to enhance the upward motion the excess heat delivers.
   – Planting vegetation in the median strip will slow transport of pollution from the upwind lane into the downwind lane, further encouraging vertical motion. The additional advantage of vegetation is that it acts as a deposition surface for the very fine and especially ultrafine particles.
   – Design or redesign the roadway or intersection by placing the entire roadway in a cut section as part of an elimination of the intersections.
   – Barriers between the right-of-way and the receptor can force air up and generate mixing, lowering concentrations by dilution, or removing the particles from the air by providing surfaces for deposition, impaction, and settling. The literature is weak in this area, but one article *(Kim et al, 2005)* found that sound walls were not very effective barriers to pollution. Urban street canyons and the effect of tall buildings seem to encourage a mixing of the polluted ground level air with (presumably) cleaner elevated levels, reducing concentrations by dilution. With a line source like a highway, lateral diffusion is little help; therefore the mixing must be vertical. Turbulence is induced by a pierced barrier, which allows air to pass at some spots but not others, and this would favor an irregular barrier, not a smooth wall with laminar flow of air (and pollutants).
3. Increased distance from the right-of-way fence to receptors (homes, schools, etc.).
   – The most effective mitigation is distance, with many studies showing a 160 meter to 240 meter distance as

adequate to achieving pollution concentrations only 10 percent greater than upwind values.

4. Indoor air filtering improvements.
   – Upgrade indoor filters for homes and schools to electrostatic filters. Indoor mitigation is both the most immediate and most effective mitigation available, supported by models and data, with the potential of effectively eliminating the impact of Watt Avenue (to a few percent) in indoor air at modest cost. The HETF – UC Davis studies of 2006 showed a 75 percent reduction on very fine/ultrafine pollution at the Arden Middle School indoor site with a standard (non-HEPA) upgrade to an electrostatic filter.

North Carolina Ecosystem Enhancement Program Case Study

The North Carolina Ecosystem Enhancement Program is a joint effort of North Carolina DOT, North Carolina Department of Environment and Natural Resources (DENR), and the United States Army Corps of Engineers. The Ecosystem Enhancement Program (EEP) is designed to address North Carolina DOT's compensatory mitigation needs statewide through a cooperative multiagency effort. The program is a partnership between NCDOT, NC DENR, and the U.S. Army Corps of Engineers. It was established in 2003 and is located within the NC DENR.

The EEP provides an alternative to typical environmental planning around transportation projects by integrating natural resource issues into the transportation planning process. The program employs a proactive, long-range planning approach that involves identifying priority watersheds for protection and then assessing the impact of potential transportation projects in those watersheds. The program helps steer projects away from sensitive watersheds or parts of watersheds far in advance of project selection and design. If impacts are unavoidable, the program helps to proactively direct mitigation funds to high-value environmental projects ahead of the date when the impact will occur.

The goals of the program include:

- Satisfy compensatory mitigation requirements for authorized impacts on a programmatic, watershed-level basis;
- Provide in-ground, functioning compensatory mitigation for authorized impacts in advance of the actual impacts;
- Satisfy the compensatory wetland, stream, and buffer mitigation needs of the NCDOT Transportation Program; and
- Provide a means for organizing, steering, funding, and implementing ecosystem enhancement efforts in North Carolina.

The program was created to address a range of challenges around transportation projects and mitigation familiar to many DOTs throughout the United States. These included a large number of transportation and development projects stemming from increased growth; permitting delays due to mitigation requirements; recognition of the high cost of mitigation; and a large magnitude of impacts to aquatic resources from new road and development projects.

Prior to the EEP program, mitigation was ad hoc and the success rate (or return on investment) was uncertain. The EEP program addressed these problems by conducting statewide watershed assessments resulting in geospatial identification of watershed conditions, locations for environmental protection or restoration, and a conceptual understanding of how each project contributes to the state's broader environmental goals. Now, mitigation is directed to high-value areas and is implemented before transportation projects begin. This has removed delays due to mitigation permitting and improved the value of mitigation investments. The program also allows the state to shift mitigation from areas near the site of transportation projects to protecting potentially more valuable areas in the same watershed – although nearby areas are still preferred so that local losses of ecosystem functions are minimized.

Using information from statewide watershed planning efforts and GIS analysis, the program identifies high-value ecosystems and habitat areas based on quality of assets and degree of problems. EEP tends to focus restoration on watersheds where there are both functioning assets that can be protected and degraded areas that can be improved. This presents an opportunity to move moderately functioning watersheds in a positive direction.

The program then overlays DOT's seven-year let list of transportation projects. These are projects with a high probability of being implemented. This list triggers EEP planning for restoration in 8-digit watershed catalogue units.

The overall watershed needs assessment process includes two types of analyses at two scales. EEP staff first conduct a high-level watershed screening analysis that allows them to make informed selections of watersheds that will be the subject of more detailed work. The approach is applied to 14-digit HUCs within 8-digit catalog units and relies heavily on GIS assessment. Once a short list of watersheds has been developed based on the GIS analysis, EEP staff conduct a more detailed analysis of the candidates to further refine the selections and focus in on key functions: water quality, habitat, and hydrology. This additional analysis includes a field review of the watershed and discussions with local governments, resource professionals, and interested parties. The future potential threats and other attributes also are investigated. The goal of this step is to gauge local interest in a watershed planning effort and to evaluate whether it appears that the watershed of interest will yield restoration opportunities. This allows for the development of comprehensive recommendations to address watershed needs.

EEP staff apply five broad categories of information to evaluate each 14-digit watershed within an 8-digit catalog unit. These are: baseline watershed descriptors, watershed resources or assets, watershed problems, potential threats and stressors, and other factors of interest. The statistics associated with baseline descriptors, assets, and problems are compiled and presented in a watershed attribute matrix which provides these data for all 14-digit watersheds within the 8-digit watershed catalogue units. Table A.4 lists the specific data used to screen watersheds.

One objective of the EEP is to provide a consistent and streamlined approach to address compensatory-mitigation requirements associated with Section 401 and 404 permits and Coastal Area Management Act permits issued by the N.C. Division of Water Quality, the U.S. Army Corps of Engineers, and the N.C. Division of Coastal Management. By consolidating the mitigation requirements of multiple small projects, EEP is able to implement large-scale watershed restoration efforts that restore or enhance water quality, habitat, and hydrology – ultimately increasing the ecological effectiveness of these projects.

EEP offers four In-Lieu Fee (ILF) mitigation programs: the Stream and Wetland ILF Program; the Riparian Buffer Mitigation ILF Program; the Nutrient Offset ILF Program; and

Category	Attribute
Baseline Watershed Descriptors	• Area – square miles • 14-digit HU number • River Basin • Linear feet of stream • Population density and distribution • General land cover information • Presence of Transportation Improvement Project (TIP)
Resource Measures/Assets	• Percent of streams buffered within 100’ • Percent Rare, Threatened or Endangered species (RTE) and Critical Habitat in the HU • Percent of stream miles with special designation (HQW, ORW, WS-I, WS-II, Tr, SA) • Percent of watershed (acres) in conservation management • Percent of stream miles designated WS-III, IV or V • Amount of fully functioning wetlands (will rely on product of the Wetlands Functional Assessment Team to gauge this) • Amount of fully functioning streams (will rely on product of the Streams Functional Assessment Team to gauge this)
Existing Problems	• Percent of stream miles not buffered (100’) • Percent of stream miles impaired • Percent streams 303(d) listed waters • Percent impervious surface • Amount of functional wetland loss (will rely on product of the Wetlands Functional Assessment Team to gauge this) • Amount of functional stream loss (will rely on product of the Streams Functional Assessment Team to gauge this)
Future potential threats/impacts	• Significant anticipated growth – residential, commercial, industrial
Other factors	• Presence of restoration projects (represents and opportunity to build on existing efforts) • Previous Local Watershed Plan (LWP) study area? (If study was recent, it may be too early to return to that specific watershed.) • Data rich area? (Areas with significant data are favorable.) • Local interest? • TMDL (total maximum daily load) study planned or under way? (Potential to partner with NC Division of Water Quality on development and implementation of a TMDL.)

Table A.4. Watershed Attributes Evaluated During Screening Analysis

the NCDOT Stream and Wetland ILF Program. Applicants make payments to EEP in lieu of providing mitigation themselves or by other means. Upon payment, EEP assumes the full legal responsibility for planning, developing, and implementing the required types and amounts of mitigation. After successful payment, applicants are no longer liable for the mitigation associated with their payment.

Accomplishments

As of EEP's fourth anniversary in July 2007, the program had achieved some significant accomplishments.

- EEP had collaborated with public- and private-sector partners to acquire nearly 40,000 acres of natural areas, with 24 tracts being managed as public recreation areas such as parks or game lands. The tracts include about 164 miles of streams and more than 7,800 acres of wetlands in high-quality riparian and wetland areas throughout the state.
- EEP increased implementation of projects based on local watershed planning. Between January and September 2007, 76.5 percent of EEP-initiated design-bid-build projects were located in Targeted Local Watershed.
- EEP has saved the state money and has been successful in addressing NCDOT permit delays. Not a single transportation-project delay from the lack of mitigation has occurred since the initiative became operational in 2003. EEP's mitigation efforts have helped to move forward more than $3.7 billion in road building in North Carolina, with an investment of less than five percent of the construction cost of those projects.

Florida Department of Transportation's Environmental Transportation Decision-Making Process

Florida is one of the pioneering states in the development and use of general performance-based planning. The 2025 Florida Transportation Plan sets the long-range goals and objectives that guide investment decisions. An annual Short-Range Component of the 2025 Plan specifies how the goals and objectives are being measured and provides the policy framework for the department's budget and work program. Key performance measures are monitored monthly by the Department's Executive Board which has established procedures for the review, maintenance, and enhancement of all measures used by the department. Performance measures are an integral part of Florida's Strategic Intermodal System (SIS) which was established by law in 2003. SIS "represents a fundamental shift in the way Florida views the development of – and makes investments in – transportation facilities and services."

Florida also is a leader in the use of environmental performance measures. The Efficient Transportation Decision Making (ETDM) process offers an excellent example of collaborative, data-driven decision making, supported by performance measures that are designed to evaluate and streamline the implementation process.

ETDM – Florida's Streamlined Project Implementation Framework

ETDM was established by the Florida Department of Transportation (FDOT) in response to Section 1309 of the Transportation Act for the 21st Century (TEA-21) to "improve transportation decision-making in a way that protects the human and the natural environment." What began as a streamlined NEPA review framework quickly grew into a comprehensive interagency planning and project review process. ETDM links land use, transportation, and environmental resource planning in order to identify critical issues early on in the planning and programming phases, with the goal of avoiding delays and minimizing unexpected conflicts throughout the process. It is designed to expedite the process, while providing decision makers and planners with additional information at key points throughout project design and development. The ETDM program is viewed throughout the United States as one of the leading initiatives in environmental management. Key to the program's success was FDOT establishing cooperative agreements with 18 different regional, state, and federal permitting and resource agencies (as of April 2007), wherein FDOT and the agencies negotiate the necessary funding for those agencies to perform ETDM-related work. These agreements are in addition to FDOT's close cooperation with the state's MPOs, as well as two tribal governments.

Under the former transportation planning process, permitting agencies would typically wait until a project was at 60 percent design before beginning the Project Development and Environment (PD&E) process. This created a number of problems, including making the process long and drawn out, limiting the ability of project designers to consider community concerns, and identifying major issues after significant resources already had been dedicated to the project. To eliminate these problems, FDOT created two points of intervention where agencies are able to provide input, using a range of measures and input functions prior to significant engineering work: the Planning Screen and the Programming Screen. The Planning Screen occurs as cost-feasible plans are being developed. The Programming Screen occurs before projects are identified for the FDOT work program. The screening process occurs using the Environmental Screening Tool (EST), a web-based application that offers GIS mapping of over 350 data layers and several complementary data analysis functions such as querying, buffering, clipping, and summarizing of geographic data. During each screening stage, the various regional, state, and federal permitting and resource agencies have the opportunity to review a project using the EST. In the event that a conflict or adverse impact is identified, it can be addressed and/or corrected before a particular alternative gains significant momentum. Conversely, if a project is found to have little or no adverse impacts, subsequent reviews may be significantly scaled back, further expediting the process and often resulting in substantial cost savings.

The same ETDM web site that these agencies use to interact with FDOT also provides project information and updates to the public (see example, Figure A.1). While interactive public participation still takes place through traditional venues (letters, telephone calls, public meetings/workshops, etc.), the ETDM public web site provides a convenient one-stop location for advocates and interested parties to collect information on the status of an FDOT project.

Data Collection – The Florida Geographic Data Library

The ETDM process is entirely web-based, relying on the Environmental Screening Tool, which resource agencies access on-line to view project information, perform customized GIS-based analysis, offer alternatives, and present comments. All of the GIS data that forms the backbone of the EST comes from a single clearinghouse: The Florida Geographic Data Library (FGDL). Hosted by the University of Florida through extensive collaboration with FDOT, FGDL is not a primary data source, but rather a single source where data from many sources are compiled and standardized for ease of use in GIS software. According to the FGDL on-line acknowledgments page, the library currently hosts spatial data from 33 different organizations, including federal, state, and regional government agencies; nonprofit organizations; and the private sector. FGDL's over 350 data layers include such diverse topics as topography, endangered bird nesting areas, EPA toxic release sites, blood banks, prisons, transit routes, and so on *(7)*.

FDOT's EST system links directly to the data stored in the FGDL, while the agencies that contribute to the library are individually responsible for ensuring that their contribution to the library remains up-to-date. FGDL's development was largely the result of ambitious interagency projects like ETDM. As GIS data was compiled for several such projects, the effort was eventually combined into a single comprehensive source.

Project Description Report

8507 - JTA Bus Rapid Transit Lines ** Most Recent Data			
Review Start Date:	1/24/2007	Phase:	Planning Screen
From:	Jacksonville	To:	Jacksonville,"Location not available."
District:	District 2	County:	Duval County
Contact Name / Phone:	Don Dankert (800) 749-2967 ext. 7791	Contact Email:	donald.dankert@dot.state.fl.us
Project Published 5/22/2007			

Project Description Summary

The project proposes to implement a rapid transit system (RTS) to serve the transportation needs for Jacksonville and the Northeast Florida region. The proposed RTS will include exclusive transitways, bus lanes, queue jump lanes, and Intelligent Transportation System (ITS) components. The proposed improvements will lead to increased regional transit ridership and improve overall mobility for the region.

Purpose and Need Statement

Project Description

The project proposes to implement a rapid transit system (RTS) to serve the transportation needs for Jacksonville and the Northeast Florida region. The proposed RTS will include exclusive transitways, bus lanes, queue jump lanes, and Intelligent Transportation System (ITS) components. The proposed improvements will lead to increased regional transit ridership and improve overall mobility for the region.

The North-Southeast and the East-Southwest Alternatives Analysis Reports have been completed and a Locally Preferred Alternative with an alignment in each of the corridors has been adopted by the Jacksonville Transportation Authority (JTA) and the First Coast MPO. All of the corridors, North, Southeast, East and Southeast are being evaluated in this planning screen review. The Downtown project is under study as an Environmental Assessment.

A Tier 1 Environmental Impact Statement will be performed that will allow the JTA the ability to advance purchase right-of-way (ROW), in the four corridors, to be used as local match in the future if the ROW parcel is actually used in the future RTS. The result of the Tier 1 EIS will be a Record of Decision (ROD) that lists all potential ROW parcels that JTA could acquire in advance of the Tier 2 EIS for each corridor. Tier 2 EIS studies will be performed in the future for each of the corridors to define the precise alignment and associated community and environmental impacts.

The initial planning screen will provide environmental and community information to be used as a beginning for the EIS.

Figure A.1. Screenshot from the ETDM public web site.

For other users interested in gathering a wealth of GIS data for the state of Florida, FGDL also offers both a metadata navigator and an FTP site for directly accessing data of interest. Data layers are sorted between those that cover the entire state or coastal areas, and those that are county-specific.

The ETDM Performance Management Plan

In order to understand the impact of this approach, FDOT established a performance measures system, the ETDM Performance Management Plan, for the ETDM process. The Performance Management Plan is designed to continuously monitor program area performance, identify problems early, develop efficient and effective solutions, and recognize and promote successes. The goal of the Performance Management Plan is to create a more efficient and enhanced ETDM process.

FDOT began the ETDM performance measures project by creating a baseline database of existing transportation improvement projects. The database includes process information (such as permit review time and schedules met), and data pertaining to environmental conditions (such as wetlands removed and/or replaced, habitats created, noise, and air quality). This baseline database is compared with projects that go through the ETDM process to determine whether it is meeting its objectives of better decision making for the human and natural environment.

FDOT's ETDM Performance Measures Task Work Group also established specific performance measures and stated that the performance measures should be continually monitored for effectiveness and streamlining. The Performance Management Plan has three main objectives, each supported by a set of activities, performance indicators (or measures), and targets. The three objectives are: integrate ETDM into project delivery, improve interagency coordination and dispute resolution, and develop environmental stewardship through protection of environmental resources. The activities, indicators, and targets are listed in Table A.5.

The ETDM Performance Measures System has five components to provide detailed and extensive information on the effectiveness of the process. The first component is the baseline database of historical projects that will enable analysis of the ETDM system in terms of time savings, cost savings, improved project delivery, and enhanced protection of environmental resources. The second component is the list of performance measures found in Table A.5. A summary page, or "Dashboard" screens designed to look like the indicators on a vehicle's dashboard, provide an overview of the process status in terms of project delivery, interagency coordination, and dispute resolution, and protection of environmental resources through environmental stewardship. A color-coded system indicates how effectively the measure is working (i.e., a performance measurement of the performance measures): green indicates it is effective, yellow indicates potential problems, and red indicates that a problem exists with a specific measure. The third component is information gathered through the EST, providing geographically based environmental data in GIS layers. The fourth component includes information gathered through Quarterly Reports, and the last component is the Annual Report. All of these sources of information and analysis are utilized to determine how effective the ETDM process is working to protect the human and natural environment.

Florida Department of Transportation's Future Corridors Program

In 2006, the Florida Department of Transportation (FDOT) released *Florida's Future Corridors Action Plan,* which laid out the state's ambitious comprehensive and collaborative corridor planning initiative, currently under development. Future Corridors is unique because it seeks to initiate a planning process that will reach as far as 2050 and beyond. The intent of the program is to identify corridors in all modes "that will be significantly improved, transformed in function or design, or newly developed over the next 50 years." The 2006 *Action Plan* presents the need for such a program, lays out the goals and policy objectives for the program, and identifies the next steps required in getting the program running. The overall approach to Future Corridors planning emphasizes the following five principles (from page 12 of the *Action Plan*): 1) Long-term planning instead of addressing short-term needs; 2) Proactive instead of reactive investments; 3) Large-scale investment instead of incremental improvement; 4) Better integration of the planning process; and 5) A unified, policy-oriented planning process. This final point is well illustrated by the many overlapping transportation planning initiatives currently taking place in Florida. Examples of other programs that are connected to Future Corridors include the Efficient Transportation Decision Making (ETDM) program, and the Rural Areas of Critical Economic Concern designation process.

Like many of FDOT's current planning programs, Future Corridors places a high level of emphasis on collaboration, as well as on informed, data-driven decision-making. To illustrate FDOT's commitment to an inclusive and collaborative process, the agency released *Ongoing Partner and Public Involvement in Florida's Future Corridors Planning Process,* which describes the cooperative process that led to the *Action Plan* as well as the role that the public and other government agencies will play in the Future Corridor planning process. FDOT also has completed significant work in developing detailed screening criteria for evaluating potential statewide corridors for inclusion in Future Corridors planning, discussed in greater detail in the following section.

Objectives	Activities	Performance Indicators (Measures)	Targets (Percent, Number, Score, Timeframe, etc.)
Integrate ETDM into Project Delivery	(1) Implement Planning Phase (projects moving into LRTP/ Florida Intrastate Highway System (FIHS) Plans)	1(a) Percentage of major capacity transportation improvement projects screened 1(b) Percentage of ETAT agencies participating who have signed Agency Agreements 1(c) Percentage of projects with potential dispute issue(s) 1(d) Percentage of projects concept and scope revised due to ETAT review 1(e) Percentage of Planning Summary Reports completed within 90 days 1 f) Number of projects withdrawn due to ETAT review	1(a) 90 percent 1(b) 100 percent 1(c) For reporting purposes only 1(d) For reporting purposes only 1(e) 90 percent 1(f) For reporting purposes only
	(2) Implement Programming Phase (projects moving into FDOT Five-Year Work Plan)	2(a) Percentage of Major Capacity transportation improvement projects screened 2(b) Percentage of ETAT agencies participating who have signed Agency Agreements 2(c) Percentage of projects eligible for Work Program (i.e., No Dispute Issues) 2(d) Percentage of Final Programming Summary Reports completed within 60 days 2(e) Percentage of projects withdrawn due to ETAT review 2(f) Percentage of projects concept and scope revised due to ETAT review 2(g) Percentage and number of projects in formal dispute	2(a) 90 percent 2(b) 100 percent 2(c) 95 percent 2(d) 90 percent 2(e) For reporting purposes only 2(f) For reporting purposes only 2(g) Less than 1 percent
	(3) Implement Project Development Phase	3(a) Number of screened PD&Es (Project Development and Environment report) (based on focused scope of work) completed in FY 2006 3(b) Average duration of screened Categorical Exclusions 3© Percentage of screened PD&Es that obtain permits concurrent with Location and Design Concept Acceptance (LCDA) 3(d) Percentage of screened PD&Es that meet proposed schedule	3(a) At least two per district by July 2006 3(b) 12 months or less 3(c) 50 percent or more 3(d) 90 percent
	(4) Identify Funding Requirements and Efficiencies	4(a) Compare traditional PD&E study 4(b) Compare traditional PD&E schedule versus screened PD&E schedule	4(a) Cost savings of up to 20 percent 4(b) Cost savings of up to 25 percent
	(5) Develop Training	5(a) Publication of Annual Central Environmental Management Office (CEMO) Training Plan based on Incidental Take Permits (ITP) 5(b) Number and type of statewide workshops and conferences	5(a) By July 1 of each year 5(b) At least one statewide workshop each year (CEMO and ETAT)

Table A.5. Florida DOT ETDM Activities, Indicators, and Targets

Objectives	Activities	Performance Indicators (Measures)	Targets (Percent, Number, Score, Timeframe, etc.)
Improve Interagency Coordination and Dispute Resolution	(1) Implement Agency Dispute Resolution Process (DRP)	1(a) Percentage of ETAT that have a dispute and participate in a DRP	1(a) 100 percent participation
		1(b) Environmental issue that initiated dispute	1(b) For reporting purposes only
		1(c) Percentage of formal dispute resolutions completed within 120 days	1(c) 70 percent or more
	(2) Support Agency GIS database development	2(a) Provide technical support to ETAT agencies on GIS database development	2(a) Satisfaction surveys from ETAT agencies in FY 2006
		2(b) Ensure quality of the interactive ETDM database information	2(b) Annual review and acceptance of ETAT databases in FY 2006
	(3) Improve interagency communication and coordination via the Environmental Screening Tool (EST)	(3) Enhanced application of EST for functionality and communication	3(a) Annual survey of users on EST its application, innovation, and need for improvement
	(4) Development and signature of agency agreements and tribal agreements	4(a) Execution of agency agreements	4(a) 100 percent completion of all agency agreements by July 2005
		4(b) Reevaluate agency resource needs	4(b) Update agency agreements, as required, and support through budget request
	(5) Response/review timeframes for ETAT and FDOT	5(a) Percentage of ETAT reviews completed within 45 days	5(a) 90 percent
		5(b) Percentage of ETAT reviews requesting time extensions	5(b) 10 percent
		5(c) Percentage of ETAT reviews of environmental documents completed within 30 days	5(c) 90 percent
		5(d) Percentage of projects without Requests for Additional Information (RAI)	5(d) 50 percent
Develop Environmental Stewardship through Protection of Environmental Resources	(1) Environmental Compliance	1(a) Commitment compliance	1(a) 100 percent
		1(b) Percentage of projects in construction that had a noncompliance citation	1(b) 5 percent
	(2) System Level Mitigation	2(a) Earlier regional mitigation planning	2(a) Resource agency reports annually on regional mitigation plans identifying projects considered
		2(b) Earlier regional acquisition	2(b) Resource agency reports annually on projects that have approved mitigation plans prior to project development
	(3) Protection of Natural Resources	3(a) Total number of wetlands impacted (acres)	3(a) Establish baseline
		3(b) Total number of wetlands mitigated (no net loss)	3(b) Establish baseline
		3(c) Total amount spent on mitigation	3(c) For reporting purposes only
		3(d) Total amount spent on Endangered Species Act (per unit)	3(d) For reporting purposes only

Table A.5. (Continued).

(continued on next page)

Objectives	Activities	Performance Indicators (Measures)	Targets (Percent, Number, Score, Timeframe, etc.)
	(4) Protection of Cultural Resources	4(a) Total number of other findings of "effect" on which opinions are provided need SHPO input	4(a) Establish baseline
		4(b) Total number of MOAs signed	4(b) Establish baseline
		4(c) Total amount spent on mitigation	4(c) For reporting purposes only
	(5) Protection of the Physical Environment	5(a) Contamination	5(a) TBD
	(6) Protection of the Socio-cultural Environment	6(a) Enhance customer and stakeholder relationships	6(a) Customer Satisfaction Survey (80 percent satisfied)

Table A.5. (Continued).

The Future Corridors process in Florida is not yet up and running. The *Action Plan* identifies 14 potential corridor "study areas": five existing corridors that may be candidates for major transformation, and nine areas that may be candidates for the development of new corridors over the coming decades. The *Action Plan* contains a general summary of the next steps in the process, which include the creation of a statewide advisory group, initiation of prototype corridor studies, development of corridor plans, and development of financing policies.

Future Corridors Screening Criteria

Once implemented, the Future Corridors planning program will use extensive and diverse screening criteria in the identification of new corridors. These criteria, described in detail in a document entitled *Future Corridors Action Plan Implementation Guidance: Detailed Screening Criteria,* are divided into four broad goal areas: 1) Mobility and Connectivity; 2) Economic Competitiveness; 3) Community Livability; and 4) Environmental Stewardship. For each goal area there is a table consisting of a number of narrower policy objectives, and within each of these are one or more performance measures, ranging from very specific (i.e., total person-hours of delay) to entirely qualitative (i.e., a well defined vision in the regional comprehensive plan). The tables also identify the likely data sources to be used for each of the criteria *(8).*

The first two goal areas might be considered more traditional venues for the use of performance measures and data-driven decision making. The first, Mobility and Connectivity, consists mainly of measures that currently are in use at various levels of transportation planning, and depend on data sources that are readily available, such as traffic counts, origin-destination flows, and statewide and regional travel demand models. While the screening criteria do not yet include specific targets, they are linked to currently available data sources. Similarly, the Economic Competitiveness goal area consists primarily of criteria that are quantifiable and measurable based on available data sources.

The third goal area, Community Livability, presents a far trickier challenge to planners attempting to evaluate potential future corridors. Many of the objectives of Community Livability amount to avoiding physical barriers such as existing urban development, Native American reservations, or coastal areas. These "binary" criteria will be applied through the use of the Florida Geographic Data Library (FGDL), a comprehensive statewide GIS database. The remainder of the livability criteria involve qualitative evaluations related to compatibility with local planning, the comprehensive planning process, and community support. For example, the "Comprehensive Planning" criterion is divided into two parts: Degree of Regional Visioning and Compatibility with Regional Visions/Plans. The first part, Degree of Regional Visioning, lays out six guidelines for evaluating the strength of the regional planning process and the quality of the plan itself, and is to be applied during the Future Corridors project concept phase. The second part, Compatibility with Regional Visions/Plans, calls for a review of growth strategies, policy plans, and city plans (if necessary) for potential conflicts with the proposed corridor. This part is to be applied during the feasibility and environmental review phases of the Future Corridors process.

The final Future Corridors goal area, Environmental Stewardship, is directly linked to another recent FDOT program: Efficient Transportation Decision Making. ETDM is FDOT's collaborative, GIS-based environmental review process. It occurs through cooperative agreements with many other federal, state, and regional agencies and governments, and seeks to streamline and standardize environmental reviews of all transportation projects in Florida. Under the new ETDM program, resource agencies whose input is necessary for environmental review will now be involved earlier and more thoroughly. As projects progress through the planning, programming, and implementation stages, each ETDM agency, through interaction with regional liaisons, uses the web-based Environmental Screening Tool to examine, analyze, and comment on transportation projects. The Future Corridors goal area of Environmental Stewardship has the greatest number of individual criteria, all of which fall under the umbrella of ETDM. Thus, the two FDOT programs are inextricably linked.

Appendix A References

1. Specifics about these scenarios can be found here: http://www.transportation.org/sites/environment/docs/Jay%20Norvell%20Marjorie%20Kirn%20and%20Suzanne%20Marr.pdf
2. http://ice.ucdavis.edu/node/367
3. http://www.dot.ca.gov/hq/tpp/offices/ote/benefit.html.
4. http://www.mtc.ca.gov/planning/2035_plan/tech_report.htm.
5. Schrupp, D.L., W.A. Reiners, T.G. Thompson et al. 2000. *Colorado Gap Analysis Program*: *A Geographic Approach to Planning for Biological Diversity–Final Report*, USGS Biological Resources Division, Gap Analysis Program and Colorado Division of Wildlife, Denver, CO.
6. Health Effects Institute. *Mobile-Source Air Toxics: A Critical Review of the Literature on Exposure and Health Effects.* Special Report 16. November 2007. http://pubs.healtheffects.org/view.php?id=282.
7. http://www.fgdl.org/metadataexplorer/explorer.jsp.
8. http://www.dot.state.fl.us/planning/corridor/workshop113006/screencriteria.pdf

APPENDIX B

High-Value Data Investments

Environmental Factors: Water Quality and Watersheds

Synopsis of Performance Measures

The performance measures identified below capture both traditional and "future thinking" metrics on water quality and watershed health. Measures are used to model potential impacts, gauge whether proposed projects would pass environmental review, and, in general, assess compliance with the Clean Water Act, the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), and other environmental laws and regulations.

- **Water quality parameters:** Chemical, biological, and physical parameters are used to model, estimate, monitor, and manage impacts on water quality, water quality standards compliance, impaired water bodies and Total Maximum Daily Loads (TMDLs.) There are numerous metrics, spanning data on nutrients, sediment, oxygen demand, biological factors (e.g., macroinvertebrate and periphyton populations, fish assemblages, single species indicators), hydrological indicators (see also hydromodification), petroleum hydrocarbons, and others.

  Depending on the potentially affected water bodies and their designated uses, specific pollutant loads are monitored to ensure adherence to legally binding water quality standards. For example, the National Primary Drinking Water Regulations (NPDWRs) or primary standards are legally enforceable standards that apply to public drinking water systems. The NPDWRs relate to a list of specific contaminants and their maximum contaminant levels (MCLs) in the following contaminant categories: Microorganisms, Disinfectants, Disinfection Byproducts, Inorganic Chemicals, Organic Chemicals, and Radionuclides *(1)*.

  A common "roll-up" measure used by DOTs and other agencies to gauge their water quality impacts for transportation construction sites is the percent of agency projects "in compliance" versus "out of compliance" with water quality standards for downstream water bodies.
- **Hydromodification measures:** These measures are based on hydrological data and are used to model, estimate, monitor, and manage the impact on water quality, water quality standards, impaired water bodies and TMDLs, etc. due to the alteration of water bodies. These include tracking of stream widening/downcutting, physical habitat, dry and wet weather flows, flooding, and stream temperature. Hydrological data are typically geospatial and derived from in-situ monitoring.

Other less common measures are used for "beyond compliance" agency strategic planning and target setting, project alternative identification and project selection, project monitoring, and adaptive management purposes. While some DOTs and MPOs have proactively engaged in efforts to measure these kinds of parameters, doing so typically requires close collaboration with other agencies and entities that collect related data, as well as additional primary data collection and analysis. These "beyond compliance" measures include the following:

- **Impact on priority water quality protection areas:** Impact of capacity enhancement projects on nonregulated water quality in priority water quality protection areas.
- **Disturbance of riparian, floodplain, or sensitive areas:** The change in quality, quantity, location, and functioning of areas adjacent to affected water bodies that strongly influence water quality.
- **Construction related impacts:** Predicted impact on "beyond compliance" water quality during highway expansion construction.
- **Contaminants from highway runoff, stormwater, and other nonpoint sources:** Estimate of water quality impacts from highway runoff and stormwater.
- **Changes in impervious surfaces:** The estimated water quality and watershed health impact due to the additional

impervious surfaces likely to occur in a drainage basin as a result of highway capacity projects.

- **Consistency with water resource and watershed management/protection plans:** Degree of highway capacity project plan consistency with water resource and watershed management plans.

Sources of Data for Current Measures

- **Primary Data Sources:** Data on water quality parameters, including biological, chemical, and physical parameters, are largely collected and managed within state agencies, including state DOTs and MPOs, state environmental agencies (those that oversee implementation of the Clean Water Act), natural resource agencies, and sometimes, state departments of health, depending on where state-specific authority lies for water quality monitoring and related health-based requirements. Much of the data is geospatial, composed largely of GIS data layers and remote sensing data. Water quality monitoring data is often also translated into geospatial for both predictive/modeling and monitoring and ongoing management purposes. Local and regional agencies such as counties also collect and manage related data. The U.S. Environmental Protection Agency implements Clean Water Act programs (and related data collection) in a handful of states that do not have delegated authority to do so. National standards, criteria, and datasets are used as well to serve as general references and the basis or starting points for many state and local datasets and standards. Many of these national sources are listed below.
  - **The USGS National Hydrography Dataset (NHD)** is a comprehensive digital spatial dataset that contains information about surface water features such as lakes, ponds, streams, rivers, springs, and wells. Some of the anticipated end-user applications of the NHD are multiuse hydrographic modeling and water-quality studies of fish habitats. USGS also provides several analytical NHD tools on line *(2)*.
  - **303(d) List of Impaired Waters and Associated TMDL Information:** Under Section 303(d) of the Clean Water Act, states, territories, and authorized tribes are required to develop lists of waters which do not meet or are not expected to meet applicable water quality standards. The law requires that these jurisdictions establish priority rankings for water on the lists and develop action plans, called Total Maximum Daily Loads (TMDL), to improve water quality. EPA has developed reporting guidance for integrated water quality reports, including TMDL schedule development and prioritization *(3)*. A compilation of all state reports on 303(d) water bodies and TMDLs is available at the EPA web site *(4)*.
  - **State and tribal water quality standards** constitute the baseline of water quality standards in effect for Clean Water Act purposes. Any revisions determined to be less stringent must be approved by EPA prior to use in Clean Water Act programs. These standards are available state-by-state and tribe-by-tribe and are compiled by EPA *(5)*.

Other Widely Used Sources of Data and Related Tools

- **Watershed management plans.** EPA provides grant funding for watershed planning with watershed management plan requirements under Section 319 of the Clean Water Act. However, not all watershed management plans are developed under EPA funding, and because watershed management plans are developed at the local level, there is no single repository for all of these plans. A large number of watershed management plans are available at the state and local levels by searching on the Internet. Other watershed data, such as geographic location, USGS streamflow data, and relevant citizens groups, is available on EPA's national "Surf Your Watershed" webpage, described below. Watershed data also is available through each EPA Region's watershed webpage, a compilation of which is located on this page: http://www.epa.gov/owow/watershed/links.html.
- **National Water Quality Standards Database (WQSDB) Release 9.0 (December 2007)** EPA has developed a National Water Quality Standards Database (WQSDB) to improve public access to information on how the waters they care about are being protected, and how actions in their watershed can help or harm those waters. The on-line database consists of a compilation of "designated uses," used by each state to describe the functions each water body is intended to support – fishing, swimming, drinking water source, or some other use. For some states, tribes, and territories, tables and maps of uses also are available. http://www.epa.gov/wqsdatabase/
- **Impervious Surface Analysis Tool:** The Impervious Surface Analysis Tool (ISAT) is used to calculate the percentage of impervious surface area of user-selected geographic areas (e.g., watersheds, municipalities, subdivisions). The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center and the University of Connecticut Nonpoint Education for Municipal Officials (NEMO) Program developed this tool for coastal and natural resource managers. ISAT is available as an ArcView® 3.x, ArcGIS 8.x or an ArcGIS 9.x extension. http://www.csc.noaa.gov/crs/cwq/isat.html
- **Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT):** N-SPECT is a complex yet user-friendly geographic information system (GIS) extension that helps coastal managers and local decision makers predict poten-

tial water-quality impacts from nonpoint source pollution and erosion. Users first enter information about their area (land cover, elevation, precipitation, and soil characteristics) to create the baseline information. They can then add different land cover change scenarios (such as a development) to get information about potential changes in surface water runoff, nonpoint source pollution, and erosion. N-SPECT has been applied in coastal areas around the U.S., the Caribbean, Central America, and the South Pacific. It operates most effectively in medium-to-large watersheds having low-to-moderate topographic relief. http://www.csc.noaa.gov/crs/cwq/nspect.html

- **EPA WATERS Expert Query Tool:** The WATERS Expert Query Tool is a web-based application that allows users to create queries to display or extract data concerning impaired and assessed waters and associated, approved Total Maximum Daily Loads. For more information, see: http://www.epa.gov/waters/tmdl/expert_query.html
- Other data and tools for general public use:
  - **EPA EnviroMapper for Water:** The publicly available EnviroMapper for Water is a web-based Geographic Information System (GIS) application that dynamically displays information about bodies of water in the United States. It allows users to create customized maps that portray the nation's surface waters along with a collection of environmental data. Where completed, data are available on Waters, Water Quality Standards, Assessed Waters, Beaches, Sewage No Discharge Zones, and Nonpoint Source Projects. It could be used as an initial scanning tool in lieu of having a more extensive plan or database with this information at hand. For more information, see: http://www.epa.gov/waters/enviromapper/index.html
  - **Surf Your Watershed geospatial-based system** which includes watershed profiles, citizen-based groups at work in each watershed, river corridors and wetlands restoration efforts, a 303(d) list fact sheet for each watershed, links to USGS watershed information, etc. See: http://cfpub.epa.gov/surf/locate/index.cfm

Performance Data Gaps

- **Watershed data and the connectivity between water quality at particular highway-related locations with watershed health:** Watershed protection plans and related data about priority watershed protection areas/units, watershed health vulnerabilities, and watershed-level (or subwatershed unit level) watershed health metrics that can clearly be tied to highway capacity projects. Although these kinds of data are being worked on by some agencies and collaborations (e.g., see the Maryland 301 case study), most agencies are struggling with having the right data and analytical tools to plan and design highway capacity projects that protect or enhance watershed health in a clear and definable way.
- **Data on nonpoint-source pollution and related analytical tools:** Data on point source dischargers is routinely tracked and well documented under federal NPDES permitting and related regulations and rules. Today, the bigger data challenge surrounds nonpoint sources which many experts believe to be the bigger threat to water quality in addition to being significantly harder to track and manage. Nonpoint source data and analytical modeling and decision-making tools are generally lacking, yet are of great interest to parties that want to protect water quality to both attain and move beyond regulatory compliance.
- **Impervious surface information and related modeling and predictive analytical tools:** Data at the watershed and subwatershed unit levels for impervious surfaces and how highway capacity projects could or would affect impervious surfaces is needed but not readily available. This is a two-part challenge: a) having the necessary data; and b) having the tools and technologies to use the data to understand highway impacts.
- **Stormwater management data:** There is a growing consensus that improved stormwater management is critical to protecting water quality, particularly in urban areas or other areas with large percentages of impervious surfaces or other factors that contribute to significant stormwater pollutant loads. Data and tools that go beyond TMDL best management practices are needed to solve this problem because existing tools and technologies are not achieving desired water quality protection or enhancement results.

High-Value Data Investment Opportunities

The four data gap areas described above – **watershed data, nonpoint source pollution data, impervious surface data, and stormwater management data** – all pose strong opportunities for high-value data investments that could make significant strides in water quality protection beyond what already is known and practiced. Although work is being done in each of these areas, specific work that links highway capacity planning to data availability and realistic approaches for DOTs and MPOs in these areas is still needed.

The other high-value data investment opportunity is to **develop local and statewide partnerships with other agencies and entities** that collected relevant data and have a mutual interest in protecting water quality and watershed health. In many if not most areas, data, tools, and even measures exist that can help to enable project selection, planning, mitigation, etc. that will substantially enhance water quality protection over the status quo DOT approach which often considers these factors late in the process and is limited to regulatory compliance. The Ecosystem Enhancement Project in North Carolina (see case study) is one example of a cross-agency partnership that has resulted in the protection of several priority watershed areas while simultaneously resulting in significant reductions in the wait time for environmental review and permitting for state transportation projects.

Environmental Factors – Ecosystems, Biodiversity, and Habitat

Synopsis of Performance Measures

Transportation systems affect ecosystems, biodiversity, and habitat in a variety of ways, including road kill; loss and degradation of natural areas; air, water, soil, and noise pollution; and introduction of invasive species. Although some DOTs are implementing improved planning approaches to address these issues, these impacts have traditionally not been considered until the NEPA permitting process if they have been considered at all.

Species listed for protection under the Endangered Species Act (ESA) are one of the few performance measures consistently tracked by DOTs that are related to ecosystems, biodiversity, and habitat. Animal-vehicle collisions are often tracked as well. However, DOTs rarely track impact of transportation on habitat areas, consistency of transportation plans with wildlife, habitat and resource management plans, or native plant community disturbance. There are notable examples, however, where states or DOTs have made ecosystems, biodiversity, and habitat a priority, including North Carolina, Florida, California, Colorado, Maryland, and Washington. More often, these issues arise in relation to specific transportation projects and their potential impacts.

The key data needs for assessing transportation impacts to ecosystems, biodiversity, and habitat include:

- **Landscape and ecosystem data:** land use; natural areas; wetlands; lakes and streams; habitat size, quality, and location; native vegetation communities. This includes endangered or threatened ecosystems and high-quality ecosystems that are worthy of protection.
- **Species data:** Species of concern (federal and state listed species) and their life-cycle habitat needs; invasive species and degree of threat to native species.
- **Road impacts data:** road kills and chronic road kill sites; species movement/migration routes affected by roads and obstacles to movement (culverts, etc.); habitat fragmentation due to roads; water, air, soil, and noise pollution; potential contribution to further land use changes (typically from less developed to more developed).

Transportation agencies do not typically collect or maintain environmental and natural resource data beyond those they are required to have for NEPA, ESA, or other regulatory compliance purposes. Instead, this data is more commonly collected and maintained by federal, state, tribal, and local environmental, natural resource, or fish and wildlife agencies. Some private organizations such as The Nature Conservancy or local land trusts also collect and maintain some of this data.

Sources of Data for Current Measures

- **Primary data sources:** Some landscape data is available at a national level. U.S. EPA and USGS offer GIS data layers for hydrology, land use, and wetlands; U.S. Fish and Wildlife Service and NOAA Fisheries maintain lists of federally protected species. However, assessment of local and specific environmental impacts typically requires up-to-date data that has been "ground-truthed," often at a local level. State and local entities often develop higher-scale landscape data to provide increased detail and accuracy.

Other Widely Used Sources of Data

- **State Wildlife Action Plans:** Under the State Wildlife Grants (SWG) Program and the Wildlife Conservation and Restoration Program (WCRP), each state is encouraged to produce a Comprehensive Wildlife Conservation Strategy (CWCS) – or Wildlife Action Plan. Developed in consultation with local stakeholders and reviewed by a National Advisory Acceptance Team, the Plans set a vision and a plan of action for wildlife conservation and funding in each state. While fish and wildlife agencies have led the Wildlife Action Plan development process, the aim has been to create a comprehensive strategic vision for conserving the state's wildlife. A summary of state Wildlife Action Plans as well as links to contacts and more information on each state's plan is available at: http://www.teaming.com/pdf/StateWildlifeActionPlansReportwithState Summaries.pdf
- **Ecoregional Conservation Assessments:** The Nature Conservancy has produced Ecoregional Conservation Assessments for much of the United States. These are designed to identify an efficient network of lands where the viability of a region's biological diversity could be maximized by abating major threats. Assessments are systematic and comprehensive analyses that represent a new, synthetic data source for thousands of species. Most assessments include a summary report describing the assessment process and methods used, as well as a geodatabase, metadata, and schema graphic.
- **ESA Critical Habitat and Recovery Plans:** The U.S. Fish and Wildlife Service and NOAA Fisheries have designated critical habitats and developed recovery plans for many ESA listed species. These plans and critical habitat areas provide data to help guide transportation planning and mitigation.

- **Natural Heritage Programs:** Natural Heritage Programs are located in each state and are variously housed in state wildlife or natural resource agencies, universities, or as stand-alone entities. These programs maintain data and information on rare and endangered species and threatened ecosystems. They operate under the umbrella organization NatureServe, which offers a decision-support system for land use planning and resource management called Vista that 1) identifies conservation elements; 2) summarizes conservation value; 3) generates conservation solutions; 4) evaluates land use scenarios; and 5) explores sites and creates mitigation plans. Vista uses ESRI's ArcMAP 9.1 GIS mapping technology.

Performance Data Gaps

- **Data on landscapes, species, and road impacts** are inconsistently maintained across the country. Significant quantities of data related to ecosystems, biodiversity, and habitat are collected, but the collection, assessment, maintenance, and distribution of that data is highly fragmented. In any given state or location, this data could be collected and maintained by literally dozens of federal, state, local, tribal, academic, and private entities. Moreover, the datasets are likely to be kept in multiple formats and be appropriate for the limited set of purposes for which it was collected.

High-Value Data Investment Opportunities

- **Interagency collaboration/integrated planning:** Collecting and maintaining ecosystem, biodiversity, and habitat data is largely beyond the mandate, scope, and expertise of transportation agencies. In addition, numerous other entities already maintain much of this data. To address this issue, a number of DOTs have moved to an interagency and collaborative approach to transportation planning. By forming partnerships with environmental, natural resource, and fish and wildlife agencies and other entities, DOTs can leverage the data and knowledge of those entities to reduce conflicts and improve the efficiency and effectiveness of transportation planning. Through partnerships, DOTs also can seek assistance from those entities in collecting data that would be tailored to transportation needs.
- Interagency collaboration is promoted in *Eco-logical (6)* as a mechanism for developing an ecosystem approach to infrastructure development, which recommends creating a Regional Ecosystem Framework. This consists of an "overlay" of maps of agencies' individual plans, accompanied by descriptions of conservation goals in the defined region(s). A Regional Ecosystem Framework is intended to help agencies develop a joint understanding of the locations and potential impacts of proposed infrastructure actions. With this understanding, they can more accurately identify the areas in most need of protection, and better predict and assess cumulative resource impacts. A Regional Ecosystem Framework also can streamline infrastructure development by identifying ecologically significant areas, potentially impacted resources, regions to avoid, and mitigation opportunities before new projects are initiated.
- **GIS data sharing agreements and web-based GIS data access:** Transportation planners can benefit from having direct access to GIS and other data held by environmental, natural resource, and fish and wildlife agencies and entities. Because this data tends to be dynamically updated, acquiring static data layers is only partially beneficial. Some states and interagency partnerships have developed GIS data sharing agreements among agencies that allow direct access to current GIS data over the web. This provides transportation planners with up-to-date information. Examples include the Oregon Explorer web site *(7),* which provides a natural resources digital library. New York State has a statewide GIS Data Sharing Cooperative.

Environmental Factors – Wetlands

Synopsis of Performance Measures

Wetlands measures in widespread use by DOTs today focus on tracking quantity not quality of wetlands. Performance reporting confirms that throughout the nation an estimated 1,100 to 2,400 acres of wetlands are impacted annually as a result of federally funded highway projects *(8).* Two wetland-related performance measures are commonly tracked by state DOTs to support management of their wetland mitigation programs. U.S. DOT reports that 92 percent of DOTs provide the following information to FHWA annually *(9):*

- **Wetland Losses Measure:** Tracks total annual statewide wetland acreage losses as a result of transportation project construction.
- **Wetland Replacement Measure:** Tracks total annual statewide wetland acreage replaced in compensatory mitigation as a result of transportation project construction.

Use of wetland losses and replacement acreage measures, in combination, provide a useful statewide gauge of the *quantity* of impacts to wetlands associated with transportation projects. They do not, however, provide a good indication of the ecological consequences for wetlands of losses or replacements. Ecological impacts depend not just on acreages, but also on 1) the location, types, and quality of wetlands lost; and 2) the location, types, and long-term success of mitigation sites. Data on these variables is more complex to gather than basic acreage data. It is fragmentary in reach and located among many agencies, while new methods are constantly evolving to improve data availability. Use of wetland quality-related data, particularly by DOTs, is in its infancy.

Sources of Data for Current Measures

- **Primary Data Source:** Data are collected by state transportation agency environmental personnel from review and collation of information available in internal project records and other sources, particularly Section 404 permit program-related field surveys. Data reported to FHWA on or around the close of each federal fiscal year, but may easily be reported on a calendar year basis.

Other Widely Used Sources of Data

- **National Wetlands Inventory (NWI) –** A nationwide collection of digital wetlands data maintained by U.S. Fish and Wildlife Service and available for public use. Data is displayed on base maps that cover more than 90 percent of the lower 48 states. It generally shows the location, size, and function of wetlands. The maps are prepared from analysis of high-altitude imagery. Wetlands are identified based on vegetation, visible hydrology, and geography.
- **State-Level Wetlands Inventories –** Some states have created their own state-level wetland inventories, e.g., the Wisconsin Department of Natural Resources' Wisconsin Wetland Inventory or the Michigan Department of Environmental Quality Michigan Wetland Inventory that often supplement NWI information.

Performance Data Gaps

- **Data on Wetland Quality –** Traditional regulatory approaches for mitigating wetland impacts of transportation projects (and the performance measures described above) place an emphasis on mitigating the quantity of wetlands affected. A growing consensus is emerging, however, that case-by-case mitigation of "local symptoms" rather than mitigation that addresses watershed-wide issues is failing to halt environmental degradation. Federal transportation legislation now favors offsite banking mitigation, where per unit ecological benefits are usually higher than onsite mitigation.
- A watershed-wide approach to mitigation acknowledges that some wetlands have greater ecological value than others. DOTs, however, typically do not have easy access to data on the ecological value of wetlands in the vicinity of planned projects that would enable them to adopt watershed-wide planning strategies. Consideration of statewide wetland quality data early in project development would offer DOTs additional flexibility to select project alignments that both minimize mitigation costs and strengthen stewardship of the environment.
- **Data on Success of Wetland Mitigation Sites –** As many as 50 percent of wetland mitigation sites are unsuccessful. Federal regulations require monitoring of mitigation sites, however, states' monitoring practices vary and few states track mitigation site performance beyond a site-specific scale.

High-Value Data Investment Opportunities

- Develop Remote-Sensing-Based Data for Collecting, Analyzing, and Presenting Wetland Quality Data on a Regional or Statewide Scale – Wetland quality data is traditionally developed using time intensive field surveys and is therefore carried out only for site-specific locations on an as-needed basis. Remote sensing is a widespread technology that relies on various types of imagery (often taken via satellite) to enable creation of data where gathering traditional data would be impossibly time consuming.

  Several states, including Minnesota *(10)* are experimenting with use of remotely sensed data as a technique for gauging wetland quality across large regions. DOTs, as well as many other organizations, could use this information to streamline their wetland-related activities and enhance their stewardship of the environment. Work is needed to develop methods for collecting, analyzing, and presenting data. Key data development needs include:
  - Development of partnerships between DOTs and others to use remote sensing imagery to assess wetlands based on plant community structure and diversity, as determined by the pixel diversity of images detected from multispectral remote imagery;
  - Development of expertise within DOTs in the fundamentals of remote sensing (platforms, physical basis, visual interpretation, automated image interpretation);
  - Collection of appropriate photogrammetry (air and satellite photography);
  - Use of digital image processing (multispectral analysis, image rectification, enhancement, pattern recognition) software to translate imagery
  - Raster analysis (data analysis, overlay, spatial characterization); and
  - Approaches for presenting information in ways that are useful to project developers at DOTs and their resource agency partners.

Remote sensing imagery offers a credible baseline of information to evaluate alternatives early in the process [of NEPA], and eliminating unnecessary and costly detailed analysis.

- **Develop Data for Tracking Statewide Effectiveness of Wetland Mitigation Sites.** North Carolina DOT's moni-

toring program provides an example of site-specific data reporting *(11)*. Washington State DOT is now reporting statewide mitigation success rates and might offer a model for development of suitable measures. Key data development needs include:
  - Selection of appropriate biological and hydrological measurement metrics for measuring success over a mitigation site's lifespan;
  - Securing resources to cover costs of collecting data;
  - Development of easy-to-use but accurate yardsticks that provide a gradient between "success" and "failure," based on analysis of many variables; and
  - Data storage and reporting mechanisms.

Wetland mitigation site success rate data offers an emerging tool for evaluating DOTs' progress as effective environmental stewards.

Environmental Factors – Environmental Health

Synopsis of Performance Measures

Environmental health typically refers to the impact on human health and well being due to physical, chemical, biological, and other components of the surrounding environment. While other environmental and safety factors addressed in this report have potential to affect public health, this environmental health factor focuses on air toxics – a factor that has received increasing attention in highway capacity expansion projects in recent years. Mobile source air toxics (MSAT) are a byproduct of vehicle emissions and are a known or suspected contributor to numerous cancer and noncancer human health problems. The U.S. Environmental Protection Agency (EPA) has identified six priority MSATs: acetaldehyde, acrolein, benzene, 1,3-butadiene, diesel particulate matter, and formaldehyde.

Because the science on air toxics is still evolving, there are no established criteria for determining when MSAT emissions should be considered a significant issue in the NEPA context. The FHWA issued interim guidance for NEPA documentation related to air toxics in February 2006 *(12)* which advises DOTs to limit project-specific assessments of MSATs to situations where projects are expected to result in meaningful differences in MSAT emissions between project alternatives or increases in potential public exposure to MSATs. Despite current data limitations in many areas, DOTs can benefit from tracking performance measures in the following areas to better anticipate and respond to air toxics issues and concerns that may arise related to highway capacity expansion projects:

- **Concentrations of Six Priority MSATs:** Tracks monitored and/or modeled air quality status related to six priority MSATs. While the focus of DOT measurement activities should be on tracking air toxics emissions associated with mobile sources and capacity expansion plans, it is increasingly important for DOTs to track (and in special circumstances, collaborate on) environmental agency efforts to monitor ambient air toxics concentrations.
- **Proximity of Vulnerable Populations Potentially Affected by MSATs:** Tracks the amount and location of potentially vulnerable populations (e.g., housing units, schools, hospitals, nursing homes) proximate to highways or major roadways. Proximity of sensitive receptors to highways and major roadways can be an important planning factor since air toxics concentrations tend to tail off rapidly within 300 meters of roadways.

In many areas, ambient monitoring of air toxics concentrations is not currently available and such monitoring may not be feasible for state or local environmental agencies to collect given current priorities and resources. In these situations, emission inventories and modeling are the primary source of information on local or regional air quality status related to MSATs. The proliferation of air toxics monitoring activities (including near-roadway studies), however, are increasing the availability of data for analysis and benchmarking of local and regional air toxics air quality status.

Even when information on ambient concentrations of air toxics (monitored or modeled) is available, challenges exist with translating this information to assess public exposure and associated human health risks. While many MSATs have documented cancerous and noncancerous health effects, it can be difficult to determine program or project-specific risks from this information. Even while understanding of MSAT health effects is evolving, however, information on the efficacy of various near-road air toxics mitigation measures is growing, as illustrated by the Watt Avenue, Sacramento, California case study highlights.

Sources of Data for Current Measures

- **Primary Data Sources:** MSATs are a relatively new and emerging area for data collection, analysis and performance measurement in the context of transportation planning and projects. Data on air toxics emissions and increasingly on ambient concentrations of MSATs are collected by EPA and state and local environmental agencies. The availability of information on human health risk varies for each MSAT. Scientific studies are used to develop Unit Risk Factors that can translate ambient concentrations into cancer-related health risk estimates. Reference Concentrations also are commonly set to assess when noncancer health effects may occur.

Information on the proximity of sensitive receptors in transportation corridors is collected by some transportation and environment agencies and is often a component of geographic information systems (GIS) supporting transportation, land use, and environmental planning.

Potential Sources of Data

- **National Air Toxics Assessment (NATA) and Emissions Inventories –** EPA conducted National Air Toxics Assessments (NATA) in 1996 and 1999 to evaluate the distribution of air toxics across the United States *(13)*. The NATA data were used to compile national emissions inventories on air toxics, estimate air toxics levels across the nation, estimate population exposures, and characterize public health risks. EPA also seeks to estimate the national levels of air toxics through its National Emissions Inventories (NEI) *(14)*. NEI includes estimates of HAP emissions from mobile sources. EPA has developed compilations of NEI data for 1996, 1999, and 2002, and is working to provide additional compilations every three years. State and local agencies also may assemble air toxics emission inventories on a periodic basis. Information from air toxics emissions inventories and modeling efforts can be highly useful to identify transportation corridors and areas where ambient air toxics concentrations may be of particular concern when considering the proximity of sensitive receptors and/or the air quality status relative to other urban areas in the U.S.
- **National Air Toxics Trends Stations (NATTS) Network –** EPA launched a national air toxics data monitoring effort in 2004, which is referred to as the National Air Toxics Trends Station (NATTS) program. The NATTS program currently is comprised of 25 monitoring sites in urban areas across the U.S. and generates data regularly on ambient concentrations of 21 air toxics, including the six priority MSATs. The EPA-sponsored Urban Air Toxics Monitoring Program (UATMP) is another important source of ambient air toxics monitoring data, which currently includes air toxics monitoring data for 59 sampling sites in urban areas *(15)*. Some state and local environmental agencies also make their own air toxics monitoring data available on-line.
- **Community-Scale Near-Roadway Air Toxics Studies –** Information from an increasing array of site-specific studies of near-roadway air toxics concentrations and associated health effects are becoming available. EPA's community-scale air toxics monitoring grant program is providing funding to state and local agencies to conduct air toxics monitoring to better assess air toxics concentrations and health risks from sources such as roadways, rail yards and ports. FHWA also is supporting pilot studies on transportation-related air toxics issues in Nevada, North Carolina, and Michigan. Several other studies are being conducted in California by parties, including UC Davis and by the Air Resources Board and Caltrans. While the findings from these and other site-specific near-roadway studies may not be easily transferable to other locations, it is anticipated that findings from these studies will increasingly inform public comments on DOT planning and projects across the U.S. Data from these site-specific studies can be used to inform qualitative risk assessment by DOTs, as well as to inform assessment of potential mitigation measures that could be proposed to address potential air toxics "hot spots" near vulnerable populations.

Performance Data Gaps

- **Data on Ambient Air Toxics Concentrations –** The availability of data from air toxics monitoring is limited in many areas of the U.S. While some states, such as California, have extensive air toxics monitoring programs and networks of sampling sites, many other parts of the U.S. have limited monitoring data. Even if there is a monitoring station located in an urban area, its proximity to a particular transportation corridor and other confounding factors (e.g., meteorology, effects of stationary sources of MSATs) can severely limit the usefulness of available monitoring data.
- **Data on Impact of Vehicle Fuel Mix Changes on Air Toxics –** There appears to be substantial uncertainty regarding how changes over the next few decades in fuel mix and vehicle types will impact the prevalence of different MSATs. While experts anticipate that cleaner vehicles and cleaner fuels will substantially decrease mobile-source air toxics emissions, changes in fuel mix may result in significant increases in certain individual MSATs even while overall air toxic emissions are declining.
- **Data on Human Health Risks Associated with Exposure to MSATs –** While the prevalence of studies on cancer and noncancer health effects of exposure to various MSATs is increasing, many uncertainties remain. In 2007, the Health Effects Institute released a report on the state of research on exposure and health effects associated with MSATs *(16)*.

High-Value Data Investment Opportunities

- **Develop Local Partnerships to Monitor MSAT Concentrations –** Exploring partnerships with state and local environmental agencies and EPA can enable cost-effective ambient monitoring of near-road air toxics concentrations in key areas of concern. In many cases, data already may exist through emerging sampling and trends sites. For urban areas where no monitoring exists, partnerships with state and local environmental agencies can be used to leverage EPA resources for monitoring through the NATTS program or the Community-Scale Air Toxics Monitoring grant program. There also is an opportunity to expand on the work being done by UC Davis to study the efficacy of various cost-effective measures to mitigate near-road exposure to MSATs through additional pilot studies.

- **Conduct Meta-Analysis of Site-Specific MSAT Studies –** The proliferation of pilot projects to assess the prevalence and health effects of MSATs, including the FHWA-sponsored studies, are providing increasing opportunities to look across existing and emerging studies to assess patterns and the extent to which findings may be transferable. In the future, it may not be necessary to invest in near-road air toxics monitoring in areas where cost-effective "best practice" mitigation measures can be proposed to address public concerns related to air toxics "hotspots."
- **Improve Data on MSAT Exposure and Health Effects –** The Health Effects Institute's November 2007 review of the literature on MSAT exposure and health effects makes a series of recommendations for improving the state of knowledge. While many of these recommendations are outside the purview of DOTs, dialogue and partnerships with public health and environment agencies can help to advance some of these efforts to improve understanding of MSAT health.

Environmental Factors – Climate Change

Synopsis of Performance Measures

Climate change measures are only beginning to be introduced as part of state DOT and MPO decision making, and there is not yet a consistent approach to climate change data and model projections. Climate change considerations for transportation include two distinct areas that require different information and measures:

- **Greenhouse Gas Emissions from Transportation Measures:** Assesses the actual or projected levels of greenhouse gas emissions from existing or proposed transportation projects; and
- **Impacts of Climate Change on Transportation Measures:** Assesses the risk and vulnerability of transportation systems and facilities to the effects of climate change.

Greenhouse Gas Emissions from Transportation

A growing number of states and regional governments are beginning to track and calculate greenhouse gas (GHG) emissions from mobile sources. Over 35 states have set Climate Action Plans that include either goals or specific targets for reducing transportation GHG emissions. Some plans focus on travel demand strategies; while others focus on fuel efficiency, introduction of alternative fuels, and vehicle technologies to reduce consumption of carbon-based fuels. Most notably, California has passed legislation creating light-duty vehicle GHG standards to take effect beginning in 2009 and phased in through 2016. The emission standards apply to the full fuel cycle and will result in a 34 percent reduction in GHG emissions from passenger cars and light-duty trucks and a 25 percent reduction in emissions from light-duty trucks. Roughly a dozen other states, including most of the Northeast states as well as Florida, have adopted California's GHG standards along with the California Low-Emission Vehicle (LEV) standards for criteria pollutants and precursors. The standards have not yet been implemented, however, due to legal challenges. The U.S. Environmental Protection Agency is developing a draft rule regarding GHG emissions through fuels and technologies.

Measures of greenhouse gas emissions can be generated at a system level by measuring fuel consumption and calculating the levels of carbon dioxide and other GHGs emitted by the burning of carbon-based fuels. At the project level, rough measures of emissions can be derived based on estimates of vehicle miles of travel (VMT) and fuel economy. Much of this information currently is available. More accurate estimates would incorporate information on average speeds, drive cycles, and vehicle types as well. Generating this information requires more complex assumptions and/or use of more advanced models or microsimulation.

Impacts of Climate Change on Transportation

Measures of risk to climate change require the integration of multiple factors regarding the location and condition of infrastructure, the probability of impact, and the degree of severity of individual and cumulative impacts of climate factors. Typical climate factors include changes in:

- Temperature (average annual temperature and daily extremes);
- Precipitation (average annual precipitation and intensity of individual rainfall events);
- Sea level rise;
- Storm surge;
- Severe storm activity (including frequency of severe storms as well as the intensity of individual storm events);
- Coastal and inland erosion;
- Ice and snow melt; and
- Permafrost condition (range, thawing).

The climate factors relevant to a DOT vary according to the region involved. To assess risk to transportation infrastructure and services, data on these climate factors is incorporated with information about facility condition, location, and level of significance to mobility and service continuity.

Sources of Data for Current Measures

- **Primary Data Source, Greenhouse Gases from Mobile Sources:** Fuel consumption data is available through annual reports generated by the Energy Information Agency of the U.S. Department of Energy, as well as from individual state reports. VMT data is tracked by individual DOTs, and VMT projections are developed by both state DOTs and regional planning agencies through travel demand modeling. Fleet composition and vehicle fuel economy data is maintained by the U.S. Department of Transportation, and by individual states.
- **Primary Data Source, Impacts of Climate Change on Transportation:** Information on both the location and condition of infrastructure facilities (highways, airports, transit facilities) is maintained by a variety of state and local transportation agencies. Private-sector owner/operators maintain data on location and condition of ports, railroads, and freight facilities. Trend information on temperature, precipitation, and storm activity is maintained by the National Climatic Data Center of U.S. NOAA, as well as by state Offices of Climatology. Climate model projections are conducted by NOAA research offices, including the Center for National Climatic and Atmospheric Research (NCAR); NASA; and other federal agencies. Federal climate research across federal agencies is coordinated by the U.S. Climate Change Science Program.

Other Widely Used Sources of Data

- **Conditions and Performance Report –** The U.S. Federal Highway Administration issues annual reports on the condition of surface infrastructure through its Federal Highway Statistics, Conditions and Performance, and Highway Economics Reporting Systems Reports. Other modal agencies issue parallel reports.

Performance Data Gaps

There are several data gaps that need to be addressed to accurately assess performance on climate change.

Greenhouse Gas Emissions from Transportation

- **Alternative fuels emissions data** – While current direct (tailpipe) emissions are well understood, the shift toward nonpetroleum fuels (e.g., ethanol, biofuels) has led to increasing uncertainty due to fuel life-cycle emissions. While models are available to estimate these emissions, the growing role of alternative fuels will continue to increase uncertainty in this area.

Impacts of Climate Change on Transportation

- **Region-level projections for changes in climate conditions** – Several global circulation models (GCMs), recognized by the Intergovernmental Panel on Climate Change (IPCC) are available that provide global projections of climate change. These models are used by researchers to generate projections at national and regional scales. As modeling science progresses, the ability to generate regional-level climate scenarios is advancing. A combination of trend information with potential climate scenarios can provide useful ranges of potential impacts that can be used for transportation decisions. However, the current state of science involves levels of uncertainty that preclude specific projections at more localized scales.
- **Standardized data on locations and elevations of infrastructure** – Information is often not readily available regarding both land elevations and actual infrastructure elevations, or is not yet available in geospatial format. This information is critical in coastal areas and other sensitive locations.
- **Standardized geospatially based data on environmental trends** – While data on environmental trends is collected and available from science and resource agencies, it is often not readily usable by transportation agencies. Improved packaging of data in terms of scale, geographic/political boundaries, and geospatial coding would greatly improve the usefulness of environmental trend data.

High-Value Data Investment Opportunities

Greenhouse Gas Emissions from Transportation: Improve Life-Cycle Modeling and Travel Activity Behavior Models

Two primary areas of data improvement are required to enhance GHG emissions tracking and benefits analysis.

- Life-cycle models: Life-cycle models of GHG emissions still require improvements to understand the tradeoffs available in fuel policies.
- Travel behavior: The effectiveness and cost effectiveness of travel activity behavior pattern measures, especially with regard to externalities, is still not well understood. Better grasping of the implications of these two areas is critical to best reducing GHGs from transportation.

Impacts of Climate Change on Transportation: Develop Geospatial Data Integrating Transportation Information with Environmental Trends and Climate Change Projections

A geospatially based platform to integrate transportation and climate information would support DOTs in identifying infrastructure at risk and selecting and prioritizing adaptation and investment strategies. These integrated datasets would include the following:

Transportation Data

- Location of transportation facilities, including roads, railroads, airports, ports, and intermodal facilities;
- Location of emergency evacuation routes;
- Land and facility elevations; and
- Location of protective structures (levees, dikes).

Environmental Trend Data

- Precipitation levels (seasonal averages and patterns of intense rainfall events);
- Temperature (seasonal averages; extreme highs and lows);
- Relative sea level rise;
- Storm surge heights; and
- Location and duration of flooding events.

Climate Scenario Projections (model-based scenarios of ranges of potential climate change based on assumptions of emission levels)

- Precipitation levels (seasonal averages and patterns of intense rainfall events);
- Temperature (seasonal averages; extreme highs and lows);
- Relative sea level rise (integrating subsidence and sea level rise resulting from thermal expansion and ice melt); and
- Severe storm frequency and intensity.

Storm Surge and Flooding Scenarios

- Storm surge heights at various levels of storm/hurricane intensity; and
- Areas of inundation at various levels of extreme precipitation.

Development and analysis of this data will require interdisciplinary partnerships between transportation and environmental agencies. The following steps should be taken to advance this area of measurement to support more robust risk analysis and planning, and to track agency success in ensuring reliable performance and protecting transportation assets:

- Develop partnerships between DOTs and regional planning agencies with environmental agencies and climate researchers to develop agreement on data requirements, standards, and geospatial integration
- Develop probabilistic risk assessment methodologies to incorporate risk, vulnerability, and uncertainty into siting, design, and investment decisions
- Develop approaches for presenting information in ways that are useful to planners, project developers and design engineers, operations and emergency management personnel, land use planners, and environmental/science agency partners.

Community Factors – Land Use

Synopsis of Performance Measures

One broad category of land use measures involves the land "consumed" by a project or program of projects – either directly as a result of the project's footprints, or the indirect impacts of induced growth/development associated with the project. At a project level, it is common to measure direct impacts of the project, and for major capacity investments the estimation of indirect impacts is becoming more common. Land use measures also are commonly used at a regional level in long-range planning, especially the amount of land consumed for urban development as a result of a given transportation land use scenario or plan. Land consumed by or lost to a project or its indirect impacts can be broken down by the specific type of land (e.g., agriculture, forest, wetland, vacant, developed).

Direct impacts are relatively easy to evaluate and simply require information on the land use or land cover for the project area, as well as the project footprint. Indirect impacts are much more challenging, as they require a method of forecasting the specific growth impacts of a project (general location and density of development). Land use forecasting models and methods, however, are better suited for examining general trends in development patterns rather than predicting the precise spatial impacts. Furthermore, simple forecasts of "land consumed" do not evaluate the underlying value of the land for ecological or human purposes, and people may place different values on any given type of land use. Because of the difficulty inherent in forecasting indirect land use impacts and the subjectivity of whether many land use impacts are considered "good" or "bad," land use impacts are often evaluated from a qualitative rather than a quantitative perspective.

An alternative set of land use performance measures evaluates the consistency of the project with local and/or regional land use plans and policies – for example, whether the project serves a designated growth area, or is likely to induce growth consistent with local and/or regional objectives for growth. If growth policy areas have been designated, quantifiable measures can be defined to determine whether the project is inside or outside such an area (although this does not address the question of whether the project will actually induce growth in the desired policy area). Otherwise, the assessment of these measures typically is done from a qualitative, descriptive standpoint.

Sources of Data for Current Measures

Local jurisdictions (e.g., counties and cities) typically maintain data on both existing and planned land use by category. Such data were traditionally kept in the form of a hard-copy map, but now are maintained by most jurisdictions in electronic format. In an increasing number of metropolitan areas, the MPO or other regional planning agency has aggregated local land use data into a regional database for regional planning purposes, although this database may or may not be updated regularly. Existing and planned land use data is most often maintained at a polygon level. Local jurisdictions (and sometimes regional agencies) also maintain parcel-level data, used for tax assessment purposes, which include information on existing land use (type of use, square footage, value, etc.) Land use data are often inconsistently categorized across jurisdictions (e.g., different density or use categories), and may not be available in rural areas, especially those lacking comprehensive plans or zoning. Therefore, aggregating data across a project study area can sometimes be a challenge.

Environmental databases of land cover (e.g., forest, grassland, cultivated, urbanized), wetlands, natural areas, and other natural features represent an additional source of land use data to augment the local sources which consider primarily human and urbanized uses. [The term ‘land use’ typically refers to the purpose for which humans are using the land and can be distinguished from the term ‘land cover’, which emphasizes the natural or artificial coverage of the land (forest, grassland, wetland, agriculture, etc. with “urbanized” typically one all-encompassing category).] These data are typically maintained by a state or national environmental agency. Examples include the National Land Cover Map and hydrography (surface water and streams) by the U.S. Geological Survey (USGS). Wetlands and other environmental data are discussed under separate topic areas.

Orthophotography (aerial photos corrected for terrain and spatial location) represents an additional source of land use data, which may be used on its own for visual inspection, or processed to identify different types of land uses and land cover. Orthophotography also is available from the USGS.

Land use forecasting models are a source of data on future land use. Most models (such as UrbanSim, MEPLAN, and TRANUS) operate at a relatively coarse level (e.g., population and employment by regional subdistrict or traffic analysis zone), although tools such as UPLAN have been developed to disaggregate land use forecasts to a more detailed level for policy analysis purposes. Scenario planning models such as INDEX, CommunityViz, and PLACE3S can be used to develop land use measures for different future scenarios, and a number of custom models or planning tools have been developed throughout the country (e.g., LUCIS in Florida).

Performance Data Gaps

Data on existing land use are generally quite good, except in some localities (primarily rural areas or smaller communities) where local jurisdictions do not conduct land use planning or maintain comprehensive land use plan data. As previously noted, however, aggregating data into a consistent format across multiple jurisdictions can sometimes be a challenge.

For tracking land use changes over time, systems are needed to ensure that land use databases are routinely updated to reflect new construction or other changes in use. A small but growing number of areas have comprehensive tracking systems that allow factors such as land conversion and the type, density, etc. of uses at a small area level to be monitored on a timely basis. Without such a system in place, it can be difficult to evaluate actual growth patterns (e.g., amount inside versus outside policy areas) on a timely basis.

As previously noted, land use forecasting methods generally involve quite a bit of uncertainty. Furthermore, robust models can be time-consuming and resource-intensive to develop. While the state of the practice is improving, there are inherent uncertainties related to the difficulty in predicting human behavior which, combined with the level of effort required for comprehensive data collection and model development, mean that forecasting of land use impacts is likely to remain an imprecise activity in the foreseeable future.

High-Value Data Investment Opportunities

At a metropolitan area level, efforts to integrate local land use data into a regional view have proven extremely valuable for regional planning efforts as well as project or corridor planning efforts that span multiple jurisdictions. Further data integration efforts should be encouraged, along with systems to maintain regional databases with real-time updates from local jurisdictions. Because land use data collected and maintained at the county and city level are usually collected at different resolutions using different classification schemes, agreement on a common generalized regional land use classification scheme would be of great value. Innovative institutional arrangements to build interjurisdictional and interagency partnerships for data collection and integration could be pursued in order to achieve success in this area.

Data integration should include geospatial tracking of building permit data to support monitoring of land use changes over time. Satellite imagery can be used for routine verification of land use changes. Portland Metro’s Regional Land Information System (RLIS) is an example of a regional data integration system that includes existing land use, building permits, planned land use, and other data at a parcel level. RLIS has been used to compare actual with planned population and employment growth in designated growth centers, and to track the density and location of new development in the region.

Remote sensing, based on aerial or satellite imagery, is a promising source of data on existing land use/land cover, especially describing the physical features of the use. Remote sensing has been used to develop land use databases in areas where local data are inadequate or an inordinate amount of effort would be required to aggregate databases. It also may be used to develop metrics of the design of the built environment, such as building coverage, parking lot coverage, setbacks, transportation facility widths, etc. that may relate to transportation and/or environmental impacts.

A final area for leveraging existing data is public/private sector agreements that enable access to privately maintained land use data (such as real estate records.) Models for ensuring protection from disclosure of proprietary data and for creating value propositions that enable this type of data sharing would be of value.

Community Factors – Archeological and Historical Sites

Synopsis of Performance Measures

Federal agencies are required to preserve and enhance cultural resources, including historic and archeological sites of significance. Transportation officials are required to work with federal and state agencies to identify historic properties that could be affected by a transportation project, and explore what those effects are likely to be. A discussion of the likely effects on historic sites is a requirement in the environmental documentation. The level of detail of this discussion must be on a scale related to the importance of the properties, and the expected impact of the project on those properties.

To meet these regulations, most DOTs address impacts to historic, cultural, and archeological resources through the NEPA process, where it is required *(17)*. In addition to NEPA, Section 106 of the National Historic Preservation Act requires that federal agencies identify sites in a project area that are listed in, or are eligible for, the National Register of Historic Places, determine how any sites may be affected by the proposed project, explore alternatives to lessen any negative impacts, and work with the State Historic Preservation Officers and/or the Tribal Historic Preservation Officers to reach an agreement about employing measures to mitigate the anticipated effects. Under this legislation, federal agencies are required to allow the Advisory Council on Historic Preservation an opportunity to comment on all projects affecting historic properties either listed in, or determined eligible for listing, in the National Register.

Measures

The measures used by DOTs to fulfill the requirements in the NEPA and Section 106 process are typically binary and qualitative. These questions are typically answered to meet the requirements:

- Will the project have adverse or beneficial effects on historic or cultural resources?
- Will the project have substantial impacts to Indian trust resources or sacred sites?
- How will any adverse effects be mitigated?

Sources of Data for Current Measures

- **Primary Data Source:** Data used by DOTs for this process is available through the National Register Information System *(18)*. This on-line database lists all properties on the register and provides street addresses and links to any other pertinent information. Another source of information is the State Historic Preservation Office (SHPO). These offices manage the process of surveying, evaluating and nominating historic buildings, sites, structures, districts and objects for the National Register. Beyond this basic function, SHPOs vary in the type of information they provide.

Other Widely Used Sources of Data

- **Department of Defense Agencies –** Some department of defense agencies manage historic properties under Section 110 of the National Historic Preservation Act, and some have developed GIS databases to be able to map these sites. The U.S. Army Air Force has developed a Cultural Resources Geospatial Data Integration, Air Combat Command which is a model GIS that will be implemented through the Internet.
- **GIS-Based Cultural Resource Databases –** An increasing number of DOTs with cultural resources databases are utilizing them in a GIS format, enabling them to map the locations of the sites and conduct spatial analysis. Historic site data layers can be combined with environmental layers to conduct locational analyses on more than one factor in this framework. Pennsylvania, Wyoming, and New Mexico are three examples of states with cultural and historic resources GIS databases and mapping capabilities.
- Historic Property Screening Tools (HPST) – The Historic Property Screening Tool (HPST) was developed through a National Cooperative Highway Research Program (NCHRP) project. HPST is a database management tool for cultural resource inventory information and historic contexts. The tool records National Register eligibility decisions and guides the user through the National Register decision-making criteria. The HPST requires that agencies adapt to a specific and consistent reporting structure.

- **Electronic Cultural Resources Evaluation Library (ECRL) –** Also developed through NCHRP, ECRL improves accessibility to National Register evaluation documents and historic contexts. The use of ECRL provides a portal where agencies can store their documentation and access documents from other agencies.
- **Archeological Predictive Models –** Locations of archeological sites are often unknown prior to project construction. Discovery of a significant archeological site can stall a project for months or more, incurring great cost and inconvenience for agencies, taxpayers and residents. However, models can be used to predict the probability of finding an archeological site on the basis of the relationships between known sites and a variety of environmental factors. These models are specific to a certain region, based on topography, vegetation, climate, other environmental factors, and known characteristics of ancient populations. Minnesota DOT had developed Mn/Model, a good example of an archeological predictive model.

Performance Data Gaps

Since this process traditionally does not happen until the project has been planned and programmed, the identification of impacts to historic sites can bring an already programmed project to a standstill, causing significant delay, an increase in costs, and lead to negative relations with stakeholder groups, tribal agencies, and communities. The key to incorporating these decisions into the process at an earlier stage is easy access to comprehensive and accurate data with locations and significance of sites. Standardizing this system through tools such as the HPST or ECRL would create consistency among states and projects. Linking this to a GIS is the next step. Finally, utilizing cultural resource data layers in conjunction with environmental data layers for alternative review during the long-range planning and preprogram studies phase would provide the most value.

High-Value Data Investment Opportunities

- **Develop Comprehensive GIS-based Tool to Incorporate Environmental, Land Use, Transportation, and Cultural Resource Data –** Many agencies are utilizing this technology, but have not integrated the analysis process. Florida's Efficient Transportation Decision-Making Process (ETDM) combines collaboration and review among agencies (including the Division of Historical Resources) with an Internet-accessible GIS application called the Environmental Screening Tool (EST). GIS analyses, approved by each resource agency, are performed for each project to identify potential impacts to resources *(19)*.

Community Factors – Social

Synopsis of Performance Measures

Most of the performance measures included in the "Social" factor have not been traditionally measured in transportation planning. Some are difficult to measure or find data for; some have just been considered qualitatively; some have only been considered in other types of planning studies. The following five measures are included in the "Social" factor:

- **Community Cohesion:** Project's impact (either positive or negative) on the sense of community that exists at the neighborhood level, and on the physical attributes that define and bound the neighborhood.
- **Noise:** Impact of noise from construction or ongoing operation of the project.
- **Visual Quality:** Overall visibility of the project, and its consistency with the surrounding visual landscape.
- **Emergency Response Time:** Project's impact on ability of police, fire, and EMTs to respond to emergencies.
- **Citizen concerns and priorities addressed by a project:** Transportation-related issues of greatest concern to citizens.

With the exception of noise impacts, which are a required consideration in the NEPA process, these measures currently are not reported in any systematic way nationwide. Federal requirements for public participation and input have lead to "citizen concerns and priorities addressed by a project" being considered in some form during project planning in recent years, though often more as part of the process rather than a separate measure.

Community cohesion impacts are not measured consistently across jurisdictions, and often not at all. They are generally incorporated into the public outreach process through delineation of neighborhoods, identification of key destinations, and primary pedestrian routes. Community cohesion impacts are usually shown as a compilation of individual factors (such as homes relocated or change in pedestrian travel times), but rarely as a single combined factor. Similarly, market research techniques have been used to assign priority scores to different projects or improvement types, based on citizens' stated priorities.

Noise impacts are part of environmental review as required by NEPA and FHWA. FHWA requires noise analysis for all Federal-aid highway projects. Current noise levels are analyzed through field surveys as well as the use of the FHWA Traffic Noise Model (TNM). TNM also is used to forecast future noise *(20)*.

Emergency response time is increasing in importance after SAFETEA-LU and increased funding and focus on safety and security. SAFETEA-LU has made Strategic Highway Safety Plans (SHSPs) a requirement for all state DOTs, and mandates that such plans be "data-driven, four to five-year comprehensive plan that integrates the '4 Es': engineering, education, enforcement, and emergency medical services (EMS)" *(21)*. Emergency response time is a component of highway safety, and any capacity project that improves response times would likely be the result of a need identified in the SHSP. Existing response times are measured through existing EMS data or through the use of travel demand models. Future response times would be measured using a travel demand model, or may be estimated based on the removal of a known bottleneck or barrier, such as a railroad grade crossing. An example of GIS-based data sources include FDOT's Sociocultural Effects analysis, which uses the Environmental Screening Tool, part of the ETDM process, to look at EMS locations.

Visual quality has not typically been measured in a transportation planning context, and there is little precedent. Some areas, particularly tourist destinations or areas where particular aesthetics are of special importance have methods for assessing visual impacts. These generally follow a method whereby scores are assigned to existing or proposed structures based on their adherence to some accepted visual standards of color, texture, reflectivity, and other physical qualities.

Sources of Data for Current Measures

Community Cohesion

- Census, state, or regional population and housing data and corresponding GIS files. MPOs and states usually have their own socioeconomic datasets. Most agencies prefer to use locally produced data when available, and supplement them with national datasets. Further, state and regional agencies that collect these data also tend to provide forecasts. These datasets are usually available on-line.
- Business location data from proprietary sources.
- Land-use datasets or tax assessment datasets are often available from local planning agencies or tax assessors. These provide locations of commercial and residential properties.
- Neighborhood association meeting records.
- Walking trip data and model results. Walking trip data may be collected by a city transportation or planning department.

Noise

- Volume, speed, and vehicle types on roadway being studied. These data come from state DOT and local or regional transportation agency traffic counts; speed sensors; travel surveys; license plate surveys; or study specific data collection.
- Type and location of existing sound barriers from the agency maintaining the roadway of interest.
- Locations of homes and population from land-use datasets, aerial maps, or site-specific data collection.
- Pavement data from agency maintaining roadway of interest or HPMS dataset.
- Field surveys of noise levels for sites of interest.
- FHWA Traffic Noise Model.

Visual Quality

- GIS data on locations of homes, land use, ground cover, elevation (contours), and location of "major landmarks."
- Site-specific data collection on predetermined visual qualities of interest, such as color, texture, or reflectivity.

Emergency Response Time

- **GIS data** on district (tract, block, etc.) boundaries; street network (GIS or traffic model); and emergency vehicle dispatch locations.
- **Existing EMS data** from local EMS agencies. These data can include EMS dispatch locations and response times.
- **Travel demand models and GIS-based tools.** Future response times would be measured using a travel demand model, or may be estimated based on the removal of a known bottleneck or barrier, such as a railroad grade crossing. An example of GIS-based data sources include FDOT's Sociocultural Effects analysis, which uses the Environmental Screening Tool (EST), part of the ETDM process, to look at EMS dispatch locations. The EST is a web-based GIS tool integrated to an extensive statewide GIS database of over 300 layers, allowing all stakeholder agencies to perform their analyses through a centralized location. It uses existing GIS web publishing technology to create a virtual project analysis environment accessible to the dozens of separate resource agencies that participate in Florida's ETDM process.

Citizen Concerns and Priorities Addressed by a Project

- Surveys, interviews, and other outreach; and
- Market research techniques are sometimes used to assign priority scores to different projects or improvement types, based on citizens' stated priorities *(22)*.

Performance Data Gaps

Much data, particularly at the project-specific level, would have to be collected for a specific study site to get a meaningful result for measures such as noise, visual quality, citizen concerns and priorities, and community cohesion. Other specific, typical data gaps include:

- **Current and forecasted pedestrian movements** are often not included in traditional travel demand models or in transportation agencies' standard data collection.

- **Information on business locations, community "centers," or residential areas** can be difficult to find at early stages and without in-depth site visits. Sometimes land-use datasets may be available, but this is not consistent nationwide. Further, these datasets may not be up-to-date.
- **Actual existing response times from EMS data** are often not readily available to planners.

High-Value Data Investment Opportunities

- **Land-use datasets** are not only useful for many of the Social measures identified above, but are increasingly important in every level of transportation planning and modeling. Increased investment by state, county, MPO, and local governments in up-to-date land-use datasets will yield increased efficiency and accuracy in transportation planning, modeling, and performance reporting. Generally, land use data, when available, is maintained by local municipalities, counties, or MPOs. At the very least, these governments often have assessors' records or zoning maps already in place and in GIS format; collecting and assembling these datasets into a land-use dataset for application to transportation studies is a fairly low-cost method in well-populated areas. For statewide or sparsely populated areas, various remote sensing technologies – which are more costly – may be required.
- Coordination with local EMS agencies, and inclusion of those agencies in stakeholder outreach, is a low-cost way of obtaining actual existing response times. Further, input of these agencies can help identify transportation investments that can improve EMS response times.

Community Factors – Environmental Justice

Synopsis of Performance Measures

Environmental justice measures attempt to examine the distributed effects of proposed transportation projects on different population groups that cut across racial, ethnic, and income groups. As such, an environmental justice measure is not a standalone measure to be developed and examined in a vacuum, but rather it entails looking at the results of numerous measures, throughout all the factor areas, to evaluate how the benefits and costs of a project – social, financial, or otherwise – differ between different groups.

In order to be applicable to this type of analysis, an indicator need only be measurable over a discrete geographic space. This "second level" measure will be highly dependent on the use of GIS analysis tools to spatially link the results of other measures to the demographics of interest. There are countless measures that could be developed in this way, and some examples include: access to jobs and markets; person-hours of delay; noise levels; air quality; and sidewalk connectivity.

It also is important to consider that project benefits and costs do not always correspond to the location of the improvement itself. The use of "select link" analysis will aid in determining who is actually using a particular section of road, which is key to assessing the distribution of positive or negative impacts. A select link analysis is performed as part of the travel demand modeling process, and identifies the origins and destinations of all users, current or predicted, of a particular roadway segment. For example, widening an existing expressway in a low-income urban community will result in negative impacts to that community: potential acquisition of right-of-way and demolition of buildings; increased noise; potentially increased pollution; and decreased community cohesion, among other possible issues. However, a travel demand model has shown substantial travel-time savings for users of the facility and increased access to job centers. A select-link analysis done during travel demand modeling can help determine the number of users from that particular low-income community, their average travel-time savings with the widened highway, and their improved access to job centers.

Sources of Data for Current Measures

Environmental justice measures will start with data and results from measures in other factors. The most important data <u>specific</u> to environmental justice are those that determine where groups of interest reside:

- **MPOs and states usually have their own standards and socioeconomic datasets.** Most agencies prefer to use locally produced data when available, and supplement them with national datasets. Further, state and regional agencies that collect these data also tend to provide forecasts. These datasets are usually available on-line.
- **The Census Transportation Planning Package (CTPP)** is a useful tool for identifying existing travel patterns by race, ethnicity, and income group as part of an existing conditions analysis *(23)*.
- **Census data** are commonly used to provide demographic information by Census tract or block.
- **GIS software and layers** are often joined with the available socioeconomic data to identify environmental justice areas of interest geographically.
- **Travel demand models** are used usually at the city or regional level to support the application of other measures, such as travel-time reduction, to specifically identified groups or geographic areas. A select-link analysis of an improved roadway, for example, can identify if users from geographically identified environmental justice zones of interest are benefiting from the improvement.

Performance Data Gaps

Using GIS to identify Environmental Justice zones of interest is fairly straightforward if using Census data, and can be done at a fairly localized level (down to the Census Block Group level). This is suitable for looking at localized impacts, such as construction impacts or air quality issues stemming from congestion.

The more sophisticated components of Environmental Justice analysis, such as travel impacts (select link analysis or CTPP origin-destination analysis) represent the more labor- and time-intensive aspects of the analysis, as most existing travel demand models do not explicitly integrate all types of socioeconomic data necessary to examine Environmental Justice-related travel impacts. Some relevant data, such as population, employment, and population by income, are typically included at the travel analysis zone (TAZ) level in a model. Other potential divisions of interest, such as racial, ethnic, or mobility impaired groups, are usually not included. These data may be divided geographically in ways that do not easily correspond to the TAZ divisions in a model. Integrating additional Environmental Justice-related geographic data into the ongoing travel demand modeling process would save considerable time and effort.

Another potential data gap is caused by the time lapse in available Census data. Implementation of the American Community Survey as a replacement for the Long Form of the decennial Census will result in more timely socioeconomic data, but many regions may wish to collect and maintain their own data sets. If a region or state currently has no equivalent to the Census datasets, establishing one would be a major undertaking; such data, however, are invaluable to public agency and private-sector analyses above and beyond transportation studies.

High-Value Data Investment Opportunities

Increased communication and interaction between transportation agencies and agencies responsible for socioeconomic data collection and forecasting would benefit the accuracy and level of detail of socioeconomic datasets. This may help to refine existing statewide or regional datasets using knowledge gained through transportation studies. Transportation agencies may get a more "hands-on" feel for conditions in a particular area, and through the course of a planning study may examine numerous different socioeconomic datasets, which may be further supplemented by surveys. Surveys can be used to gather data on:

- Local socioeconomic conditions;
- Local travel patterns by socioeconomic group; and
- Conditions or perceived conditions related to noise and congestion.

Community perceptions can be helpful in weighting various types of benefits and costs to be consistent with the values of those impacted. Before-and-after studies to evaluate whether predicted impacts actually took place after implementing a particular transportation improvement can help refine or modify existing data collection practices and analytical methodologies. Similarly, it also is important to gather information from planning documents and local surveys on previous impact-producing projects that have been recently completed. Feeding these data back into state or regional socioeconomic datasets can improve accuracy for future studies.

Environmental Justice analysis necessarily consists of a qualitative analysis component, but must be supported by high-quality socioeconomic and geographic data. Web-based GIS tools such as Florida's Environmental Screening Tool (EST) offer an ideal venue for examining applicable quantitative data in a way that allows each stakeholder agency to look at the same data in the context of their particular expertise, and then craft a thoughtful response based on all available information, quantitative or otherwise. The EST is a web-based GIS tool integrated to an extensive statewide GIS database of over 300 layers, allowing all stakeholder agencies to perform their analyses through a centralized location. It uses existing GIS web publishing technology to create a virtual project analysis environment accessible to the dozens of separate resource agencies that participate in Florida's ETDM process.

Appendix B References

1. See: http://www.epa.gov/safewater/contaminants/index.html.
2. http://nhd.usgs.gov/index.html.
3. http://www.epa.gov/owow/tmdl/2008_ir_memorandum.html.
4. http://iaspub.epa.gov/waters/national_rept.control.
5. http://www.epa.gov/waterscience/standards/wqslibrary/index.html.
6. *Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects.* U.S. DOT, Research and Innovative Technology Administration. Cambridge, Massachusetts. DOT-VNTSC-FHWA-06-01
7. http://www.oregonexplorer.info/
8. http://www.fhwa.dot.gov/environment/wetland/scanrpt/intro.htm.
9. http://www.bts.gov/programs/statistical_policy_and_research/source_and_accuracy_compendium/wetland_impact.html.
10. http://www.pca.state.mn.us/water/wetlands/cwamms.html.
11. http://www.ncdot.org/doh/preconstruct/pe/neu/Monitoring/.
12. http://www.fhwa.dot.gov/environment/airtoxic/020306guidmem.htm
13. http://www.epa.gov/ttn/atw/nata1999/index.html.
14. http://www.epa.gov/ttn/chief/net/).
15. Information on monitoring efforts can be found at http://www.epa.gov/ttn/amtic/ airtoxpg.html. Data from air toxics monitoring activities, as well as an increasing number of State and local air toxics monitoring networks, is available in EPA's Air Quality System database: http://www.epa.gov/ttn/airs/airsaqs/.
16. Health Effects Institute. Mobile-Source Air Toxics: A Critical Review of the Literature on Exposure and Health Effects. Special Report 16, 2007. http://pubs.healtheffects.org/view.php?id=282.

17. Section 4(f) of the Department of Transportation Act prohibits FHWA and other federal transportation agencies from using land from a historic site of national, state, or local significance unless there is no feasible and prudent alternative to use of the land, and actions are taken to reduce all possible harm to the site. The Section 4(f) evaluation is a requirement in the NEPA documentation.
18. For more information: http://www.nps.gov/history/nr/research/nris.htm.
19. For more information: http://etdmpub.fla-etat.org/est/.
20. For more information: http://www.fhwa.dot.gov/environment/noise/faq_nois.htm.
21. For more information: http://safety.fhwa.dot.gov/safetealu/shspguidance.htm.
22. For more information: http://www.csu.edu.au/research/crsr/PDF-files/Stolp.pdf.
23. For more information: http://www.fhwa.dot.gov/environment/ejustice/effect/crosstabs.html.

*Membership as of June 2009.

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