Southwest Region University Transportation Center

Performance Measures, Data Acquisition and Performance Evaluation Under the National Transportation System

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16. Abstract

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A major concern in the implementation of these performance measures is the data that supports them. A great deal of data is required to track the performance of the basic components of NTS analysis: major transportation facilities and regional transportation systems. Appropriate data sources for the NTS performance measures are identified, a sample of demonstration data is applied to the performance measures, and problems with data acquisition and application are discussed.

A general framework for using the performance measures to achieve the NTS policy objectives is proposed, and the implications of geographic information systems (GIS) and other technologies are discussed. Conclusions and recommendations from this research are presented.

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PERFORMANCE MEASURES, DATA ACQUISITION AND PERFORMANCE EVALUATION UNDER THE NATIONAL TRANSPORTATION SYSTEM

by

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EXECUTIVE SUMMARY

ISTEA LEGISLATION AND THE NATIONAL TRANSPORTATION SYSTEM (NTS)

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires changes in the way that transportation planning and policy-making are conducted. Essentially, ISTEA calls for transportation planning that is more performance-based and intermodal. Vehicle-oriented and mode-by-mode planning policies must give way to planning that is focused more on the user and providing accessibility through intermodal efficiency.

ISTEA also decentralizes transportation planning, giving more responsibility to agencies closer to the end user. State departments of transportation (DOTs) and, to an even greater degree, metropolitan planning organizations (MPOs) have more authority under ISTEA. To aid them in establishing effective planning, ISTEA requires that state DOTs and MPOs establish transportation management systems (TMSs) to track performance of the transportation system and assist in decision-making.

The National Transportation System (NTS) was mandate by Secretary of Transportation Federico Peña. The NTS began as an intermodal and multimodal outgrowth of the National Highway System (NHS). The NTS concept has generated a great deal of debate. This report seeks to propose a basic outline for the NTS and how it may be used.

The NTS should be an analytical tool for tracking the performance of the nation's transportation network, in its various modes, with respect to national goals of mobility, connectivity, cost-effectiveness, energy efficiency, air quality, natural resource impact, noise impact, safety, accessibility, neighborhood impact, and economic and employment impact. The NTS will be used by the federal government to aid it in setting national transportation policy. The NTS will track the performance of major transportation facilities and the connections between them in the national goal criteria listed above. In order to do this, the NTS must be based upon a set of performance measures, and good sources of transportation data.

PERFORMANCE MEASURES FOR THE NTS

This report proposes a set of performance measures to be used by the NTS, and these measures are the key component of this report. They are the means by which the NTS will analyze the transportation network's performance in terms of the national goals listed above. The performance measures are correspond to the goals listed above.

It is important to measure performance in terms of system output, that is, in moving vehicles through the network. Such measures as mobility, connectivity, and cost-effectiveness track this. However, the NTS must also be designed to measure the system's outcomes, that is, how well it allows its users to achieve their objectives, and the extent of the negative impacts of the transportation system. Such measures as energy efficiency, air quality, natural resource impact, noise impact, safety, accessibility, neighborhood impact, and economic and employment impact track these positive and negative outcomes of system use.

The performance measures used must be geared to measuring performance with respect to the users of the system. To the degree possible, they should track the effectiveness of the system in allowing passengers and goods to get from origin to destination, rather than the effectiveness of the system in moving vehicles. To this end, the measures are expressed in terms of passenger-miles-traveled (PMT) and ton-miles whenever possible.

In order to facilitate an intermodal and multimodal perspective on performance, the same basic measures should be applied to all modes. Expressing performance in terms of PMT and ton-miles facilitates this; these are basic denominators that are applicable to all modes. Due to the importance of connections between modes in an intermodal network, the performance of these connections must be tracked, and measures must be adapted to facilitate this.

Some measures, such as time or cost, will be more or less directly comparable between different modes. Other measures will not be very conducive to comparison between modes. The efficiencies and inefficiencies of different modes must be considered, and the implications of applying these measures to different modes must be recognized.

DATA REQUIREMENTS

In order to support these diverse measures for a national network, the NTS will require a large amount of data. In order to keep the cost of the NTS reasonable, it must rely mostly upon existing sources of data, and avoid any expensive data collection efforts. Existing federal, state, regional and local transportation data sources were reviewed to determine their usefulness and applicability for supporting the NTS performance measures.

Useful data sources exist at all jurisdictional levels. Local, regional and state sources will provide more detailed data that will be needed in some situations. However, gathering too much detailed data will produce a large and unwieldy database. Furthermore, the quantity, quality, and format of such data will vary between different suppliers. Good sources of data at these levels include state DOTs, the ISTEA-mandated state management systems, state environmental agencies, MPOs, municipal transportation agencies, and private transportation providers.

Federal data will be more aggregate. In some cases, this is will helpful, while in other cases this data will be too aggregate to be useful. This data, however, will tend to be more uniform. The U.S. Department of Transportation (DOT), and in particular the Bureau of Transportation Statistics (BTS), will be a good source of data for the NTS performance measures.

Other federal data sources that would be useful to the NTS include the Bureau of the Census, the Environmental Protection Agency (EPA), and the Department of Energy (DOE).

POLICY-MAKING FRAMEWORK

In order for these performance measures to be of value, the way in which they are to be used must be specified. In the vast majority of cases, project-level planning and programming will be conducted on the state, regional or local level. However, DOT still retains critical responsibilities in terms of setting national transportation policy. The NTS can supply information on the performance of the transportation system and its various modes, intermodal trip-making, and the relative efficiencies and trade-offs between different modes. The follow are the policy-making objectives of the NTS:

- System Monitoring, Identification of Weaknesses. The most basic function of the NTS is to monitor the system and to detect problems and deficiencies through threshold analysis. These thresholds will be set for appropriate system elements and criteria in order to safeguard national priorities. Thresholds may be determined by functional or infrastructure characteristics, legal or regulatory concerns, or specific national needs, such as national defense or international trade.
- Address National Goals and Problems. If the system monitoring detects a problem in the network, the NTS can be used to address it. A set of feasible policy alternatives must be generated, and the impacts of these alternatives must be forecast. A multi-criteria analysis of these alternatives can be used to select the preferred alternative. The relative weights of the various criteria may vary depending upon the nature of the problem, the policy objective, and the mode or modes.
- Progress Toward Performance Targets: The NTS can also track performance of the transportation system over time. A potential application of this is the implementation of "performance partnerships," voluntary agreements between DOT and a state or other transportation funding recipient. In exchange for the recipient achieving a certain level of performance, the recipient would be granted some incentive, such as simplified monitoring or regulation requirements.
- Support of State and MPO Planning: The NTS can also aid state and MPO planning by encouraging uniformity of data and performance measures, and by serving as a clearinghouse for data, performance measures, and planning models.

GEOGRAPHIC INFORMATION SYSTEM (GIS) PERFORMANCE EVALUATION PLATFORM FOR THE NTS

The use of a geographic information system (GIS) as a platform for the NTS is critical to its success; in fact, GIS makes the NTS proposed here. GIS is a map-based computer system designed to capture, manage, manipulate, analyze and display data. A GIS can attach data and performance measures to a map of physical, spatial components, such as transportation facilities. It can be equipped with tools for analyzing these data and performance measures. The physical, map-oriented nature of the transportation network makes it ideally suited for use with a GIS.

A GIS can be understood as a set of linked data tables, describing different aspects, or "layers," of the physical system to be described. In the case of the NTS, physical transportation network will be described by a facilities layer, which will include geographic data on two-dimensional transportation "links," such as highways, railroads, and waterways, and one-dimensional "nodes," or modal or intermodal connection points between the links. A services layer can describe the type and character of the facility, and attribute layers can contain the data and measures describing the performance of the facility or system. These layers, and their corresponding data tables, can be connected to allow flexible analysis.

GIS is already broadly used in transportation planning. Some applications include corridor and route planning, congestion management, impact analysis, and accessibility analysis. The analytical capabilities of GIS are well-suited to achieving the policy-making objectives of the NTS. Intelligent transportation system (ITS) technologies and their rigorous data collection can supplement the other data sources to help facilitate the realization of the NTS.

CONCLUSIONS AND RECOMMENDATIONS

This report has proposes the various components, functions, and features of a National Transportation System (NTS). It has discusses the legislative and institutional background of the NTS; the goals of the NTS; the set of indicators that the NTS will use as measures of performance; the data sources for supporting these performance measures; a framework for using the performance measures to inform policy-making; and the implications of a GIS platform for the NTS.

The NTS proposed here is designed to act as a unified transportation policy-making tool, applicable nationally and intermodally. As a performance-based system, its key component is the set of proposed performance measures. Most of the data required to support these measures is already collected in some form, but gathering it and applying it to policy-making will require be a major effort, and will certainly require the use of a complex GIS. Further research into the development of such an NTS should focus on finalizing performance measures, establishing data procurement protocols for obtaining the data necessary to support the performance measures, and adapting the data to the performance measures, especially for GIS databases.

ABSTRACT

The National Transportation System (NTS), an outgrowth of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), is proposed in this research as an analytical tool to guide national transportation policy-making.

The NTS must be based upon measures of transportation performance that are intermodal, user-oriented, and suitable for tracking the environmental, social, and economic outcomes of transportation system use. A set of such performance measures is proposed, and implications of the measures for various modes are discussed. This proposal and discussion of performance measures is the critical component of this report.

A major concern in the implementation of these performance measures is the data that supports them. A great deal of data is required to track the performance of the basic components of NTS analysis: major transportation facilities and regional transportation systems. Appropriate data sources for the NTS performance measures are identified, a sample of demonstration data is applied to the performance measures, and problems with data acquisition and application are discussed.

A general framework for using the performance measures to achieve the NTS policy objectives is proposed, and the implications of geographic information systems (GIS) and other technologies are discussed. Conclusions and recommendations resulting from this research are presented.

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CHAPTER 1. INTRODUCTION

The National Transportation System (NTS) is a network of transportation facilities in all modes that serve the needs of the United States for moving people and goods. The designation of the NTS was required by Secretary of Transportation Federico Peña in December 1993 as an outgrowth of the National Highway System (NHS), which is a component of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). Secretary Peña called for the additional designation of an NTS because such a system is in keeping with the intermodal mission of ISTEA, in contrast with the modally-based regime found in pre-ISTEA planning, and implied by an NHS.

The ISTEA legislation that forms the foundation of the NTS mandates transportation planning that is performance-based and able to recognize and take advantage of the efficiencies of alternate modes and of intermodal transportation. Therefore, the NTS cannot be simply a map or catalogue of high-volume transportation facilities. The NTS must also be a practical tool that can aid in setting national transportation policy. Therefore, this report proposes an NTS that also comprises an analytical system for monitoring the performance of the nation's transportation network and for supporting decisions about national transportation policy. The NTS proposed in this report would accomplish this by attaching a set of performance measures to major transportation facilities and systems in a unified national network.

In order to do this, the NTS must have as its basis a set of effective measures of performance. In keeping with ISTEA's broad goals, these measures must track not only the outputs of the transportation system, but also its outcomes, in terms of its environmental, social, and economic impacts. These must be measured in all modes, and expressed in terms of the system user, i.e. in terms of passengers and goods moved, not in terms of vehicles moved. Due to the extensive scale of the network to be monitored, the performance measures to be used must be fairly simple and general.

These measures, which track many aspects of transportation performance and are to be applied to major facilities in all modes, will provide a flexible and centralized basis for evaluating performance and making policy judgments. A set of such performance measures is proposed, and its applicability to various modes is discussed. These performance measures and their implications are the central components of this report; the discussion of ISTEA and the NTS build up to the measures, and the discussion of the data, geographic information systems (GIS), and a policy-making framework are based upon the measures.

The NTS and its performance measures require a large volume of data to support them. The scope of the data must be fairly broad to capture the outputs as well as the environmental, social, and economic outcomes of the transportation system. At the same time, the data must be fairly detailed, to track the transportation network at the level of discrete, albeit major, transportation facilities. Due to the tremendous expense of collecting the data needed for such a system, the NTS should rely as heavily as possible upon existing and emerging data sources. These sources include U.S. Department of Transportation (DOT) data, other federal data sources, state databases such as the state transportation management systems required by ISTEA, local sources, various intelligent transportation system (ITS) data gathering efforts, and any available private sector data, especially for the freight side. Many issues surround gathering the necessary data, including missing data and data in disparate formats. In order for a unified, national system to be possible, data from different sources must be converted to a fairly consistent format; the proposed performance measures serve as the structure of this format. A sample of available data, for the various modes, is obtained and adapted to the proposed performance measures.

The ideal platform for such an NTS is a GIS. The capabilities of GIS allow the mapping, analysis, and display of large amounts of data. The use of GIS also allows manipulation and data aggregation. A national, intermodal GIS would allow review of transportation performance ranging from the discrete facility level to the national system level. Such a GIS would prove valuable in tracking national transportation performance and assessing the impact of national transportation policy on system performance.

Also proposed is a framework for using the performance measurement and analytical capabilities of the NTS to guide national transportation policy. The framework is based upon the four proposed objectives of the NTS: monitoring the performance of the nation's transportation network, identifying problems and deficiencies in the network, tracking changes in performance over time, and supporting state and local transportation planning. The framework describes ways in which the performance measures may be used to achieve these objectives. The framework proposed for using the performance measures is for assessing national transportation policy and making policy-related decisions, not for transportation project programming.

Finally, conclusions are drawn regarding the proposed performance measures and their implications for data gathering, for the policy-making framework, and for the use of GIS. Recommendations are made for further development of the NTS and its performance evaluation capability.

It must be noted that this research effort has been conducted independently of DOT, and does not represent DOT views or policy. It is meant to provide options and suggestions that might prove helpful to DOT in formulating the NTS. In addition, this report does not recommend that DOT usurp any state or local transportation planning authority, or that the NTS encourage comparison between states and metropolitan areas. Rather, it proposes an NTS that is designed to assist DOT in the national transportation planning and policy-making that it must perform.

CHAPTER 2. ISTEA AND THE NATIONAL TRANSPORTATION SYSTEM (NTS)

INTRODUCTION

The Intermodal Surface Transportation Efficiency Act (ISTEA) passed by Congress in 1991 is the current federal transportation funding bill. It authorized about $151 billion in federal transportation spending over a six year period, fiscal years 1992 - 1997. It is the first major transportation spending bill passed after the near completion of the Interstate Highway system, begun in 1956. ISTEA decisively addresses a change in mission of the U.S. Department of Transportation (DOT) from building new capacity to managing and improving existing capacity. As a result, ISTEA requires that transportation planning be more efficient, more user-oriented, more multimodal and flexible in its approach to project selection, more intermodal, more cooperative, and more comprehensive in its goals. This chapter discusses the ISTEA legislation, the transportation management systems required of states by ISTEA, the need that ISTEA creates for multimodal performance evaluation under the NTS, and a general specification for the NTS proposed in this report, including the NTS's goals, objectives, and scope.

ISTEA LEGISLATION

ISTEA represents an historic shift in transportation policy and planning. Whereas previous transportation policy was conducive to mode-by-mode planning, ISTEA requires planning in an intermodal environment, with consideration of the impacts, interactions, and synergies of multimodal and intermodal trip-making. ISTEA also focuses on the demand for mobility of passengers and goods, not vehicles, and how to provide that mobility in the most efficient manner.

However, ISTEA defines its mission more broadly than simply the provision of vehicle mobility. ISTEA recognizes that transportation is not an end unto itself. The output of the system, in terms of such measures as vehicle miles traveled (VMT) or passenger miles traveled (PMT), does not fully describe the system performance. Passengers, shippers, and freight carriers rely on the transportation system as a tool, a means for achieving their desired ends. These ends may be economic or social, and must be evaluated by means other than just mobility or efficiency. Measures that track progress toward these ends include accessibility provided to desirable destinations, or the value of time saved through more efficient trip-making.

Similarly, use of the transportation system results in impacts on environmental, social, and economic conditions. Such impacts include energy consumption, air quality, impact on natural resources, safety, neighborhood integrity, employment, and economic output. Measuring these impacts is vital to accurate representation of the transportation system performance, but they are not captured by output measures either. ISTEA recognizes the importance of these outcomes of the transportation system, both positive and negative: the desired social and economic ends of the system users, and the environmental, social, and economic impacts resulting from the use of the system. Any performance planning system under ISTEA must measure these outcomes.

Another ISTEA characteristic is its apportionment of decision-making authority. A goal of ISTEA in assigning this authority is largely to decentralize it and place it in the hands of agencies closer to the end user. To this end, most decision-making responsibility is given to MPOs and state DOTs. This concentration of project programming authority at the MPO and state levels represents a change from more centralized planning at the state and federal levels, and demonstrates ISTEA's mission to allow decision-making that is more sensitive to localized needs and priorities.

Project programming under ISTEA also includes a wider variety of decision-makers than just the transportation professionals previously involved in most transportation planning. ISTEA encourages involvement of local elected officials and other leaders, planners, environmental groups, neighborhood groups, private sector freight interests, and private citizens. ISTEA's mandate for this coordinated, intermodal planning process necessitates the development of measures that allow assessment of performance in multiple modes, and for the transportation system's outcomes, in addition to its output.

ISTEA makes funding available through a variety of different programs. Although many of these funding programs are seemingly modally-targeted, another major change instituted by ISTEA is the potentially great funding flexibility. Whereas previous transportation funding bills generally allotted money strictly into modal trust funds, ISTEA allows shifting of funds between modes based on performance. For instance, National Highway System funds, nominally designated for spending on highways, can be spent on transit if it can be demonstrated that the project improves the performance of a component of the National Highway System. All told, about $80 billion of ISTEA's total allotment of $151 billion can be spent on either highway, transit, or "non-traditional" projects, such as high-occupancy vehicle (HOV) lanes (U.S. General Accounting Office [GAO] 1993, 1); potentially about $103 billion could be spent on transit (Meyer 1993b, 11).

STATE MANAGEMENT SYSTEMS

Title 303 of ISTEA requires that each state develop and implement statewide data management systems for pavement, bridges, safety, congestion, public transportation, and intermodal transportation. These management systems are performance-oriented systems for monitoring and improving transportation infrastructure and systems. They are designed to assist states and MPOs in the transportation planning process by providing a framework for investment decision-making and system impact evaluation. The management systems have the potential to form the basis for coordinated, performance-based transportation planning, and as such require a robust set of performance measures supported by a large amount of good quality data.

The management systems have some similarities to the NTS, especially in the sense that both are multimodal monitoring systems based upon measures of multiple aspects of transportation performance. As such, the management systems and the NTS can each aid in the other's development through the sharing of performance measures, programmatic design, and data. ISTEA specifies a timetable to which states must adhere in setting up their management systems. As of January 1, 1995, states are to have submitted certification statements attesting to the fact that they are implementing the management systems, along with work plans for the execution. By October 1, 1995, states are to have established performance measures and begun collecting data. And by October 1, 1996, management systems must be fully operational (Dwyer 1992, 4).

The management systems are closely related to the basic mission and philosophy of ISTEA and are critical to its success. The IMSs, CMSs, and PTMSs are especially pertinent to a number of objectives that section 134(f) of ISTEA charges MPOs with pursuing in their metropolitan transportation plans. These include satisfaction of transportation needs with existing facilities, congestion relief, access to major intermodal facilities, connectivity, efficient freight movement, life cycle cost analysis, transit improvement, and the social, economic, energy, and environmental effects of transportation decisions.

The bridge, pavement, and safety management systems (BMSs, PMSs, and SMSs) tend to be modally-oriented, and in most states build upon databases that are fairly well established. The congestion management systems (CMSs) require use of air quality data which will aid in enforcement of the CAAA. The CMSs will also address mobility issues such as volume, level of service, and travel time. The public transportation management systems (PTMSs) will direct attention to public transportation, and add an intermodal dimension to state and MPO ISTEA performance analysis.

The intermodal management systems (IMSs) offered the promise of an institutionalized intermodal focus. This would be especially valuable in monitoring and facilitating freight transportation. However, implementation of IMSs was made optional for states as a part of the bill approving the final NHS in December 1995. As a result, most state IMSs will either disappear, or will be implemented in weakened forms that will lack rigor and authority.

Agencies Involved in State Management Systems

As stipulated in the ISTEA legislation, the states have ultimate responsibility for all management systems. In the early stages of ISTEA, there was some wariness of the management systems on the part of states. Many felt that the management systems would be complex and expensive, and feared that they would be used to set high federal requirements for funding allocation and project implementation. In fact, the management systems are designed to reinforce the ISTEA values of giving more control to states and metropolitan areas and granting federal funding that can be used flexibly. The management systems are intended to provide states with analytical tools for monitoring their transportation systems and making better transportation investment decisions in an intermodal environment.

In setting up and implementing the management systems, states are expected to work with MPOs when necessary. The majority of congestion, intermodal activity, and public transportation takes place in or near metropolitan areas, necessitating cooperation between states and MPOs in establishing and operating IMSs, CMSs, and PTMSs. The management systems should also prove useful to MPOs in formulating the TIPs required by ISTEA.

A key element in implementing the management systems are the partnerships that can be formed between MPOs and freight carriers. Each partner has much to offer the other. For their part, freight carriers have great experience in intermodal planning that they could share with MPOs and states, especially for establishment of the IMSs and TIPs. Good freight mobility is also critical to the economic well-being of an urbanized area.

In order to fully realize the advantage that good freight movement can offer, MPOs must address problems facing freight carriers. Traditionally, MPOs have been oriented strongly toward passenger transportation, specifically the commuter and commuting peak time travel. Freight, however, has largely been ignored in metropolitan transportation planning (Dahms 1993b, 134). This has resulted in discontinuities in the freight network, as well as congestion and delay for freight carriers seeking access to metropolitan ports, rail terminals, truck terminals, airports, and other destinations. Future transportation planning must look at the entire trip and at all of the system's users, both passengers and freight carriers.

Implementation of Management Systems

Central to the development and implementation of the management systems are the performance measures on which their evaluations are based, and the data that in turn support the performance measures. In keeping with ISTEA's goals of user focus and trip efficiency, rather than modal focus and component efficiency, the management systems must measure performance in terms of effectiveness in moving goods and passengers over the entire trip, in terms of environmental, social and economic impacts, and in terms of cost-effectiveness and investment trade-offs.

As required by ISTEA, all states have submitted certification statements and work plans for the management systems. However, the states vary widely in their approaches to the problem of intermodal planning and in their level of sophistication. FHWA has instituted an outreach plan to monitor state and MPO progress with management systems and transportation improvement programs.

In spite of the large allocation for transportation under ISTEA, the demands for transportation spending are even greater. There is not nearly enough funding to make transportation investments in a traditional modal manner, by spending in order to satisfy projected demand in a given mode. Nor will transportation needs be served by prioritizing all projects in all modes and investing in the ones at the top of the list for as long as the money holds out. Transportation planning must focus on the most cost-effective ways to move goods and passengers in an intermodal environment. Management systems, implemented by states and MPOs, can be an essential tool for making the necessary modal trade-offs to make the transportation investment decisions that meet the mobility, environmental, social, and economic needs of the system's users. They can also aid in the development of the NTS by providing data and models for the performance measures and decision-making framework that the NTS requires.

THE NATIONAL TRANSPORTATION SYSTEM (NTS)

The ISTEA legislation gives increased transportation planning authority to states and MPOs, and calls for project programming that is more intermodal and performance-based than it had traditionally been. To this end, ISTEA funds may be transferred between modes, and state and metropolitan planning must be supported by performance-based transportation management systems. These planning conditions under ISTEA require the use of performance measures as the basis of transportation project planning at the state, regional, and local levels. By an extension of these principles to national transportation planning, such performance measures and performance-based planning could be effective for guiding national transportation policy. This concept gives rise to the proposal of the National Transportation System (NTS) of the following chapter.

The ISTEA legislation states "It is the policy of the United States to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, provides the foundation for the Nation to compete in a global economy, and will move people and goods in an energy efficient manner." The NTS can serve as the national-level mechanism for achieving this goal.

The NTS initiative began with the National Highway System (NHS) effort to map a system of roadways having national importance. Initially, the NHS was widely perceived as the "backbone" of the NTS, and the model for the design of the NTS. However, the NHS was largely an exercise in mapping the nation's most important highways, and identifying highways that qualify to receive NHS funds. Therefore, the NTS was initially perceived as a mapping of the nation's most important transportation facilities, in all modes and intermodal connections (DOT 1994a, 2).

The identification of the major facilities and their roadway connectors in conjunction with the NHS effort was seen as a major part of the NTS. In December 1993, after DOT submitted the NHS to Congress, Secretary of Transportation Peña proposed a more rigorous "national transportation system," one that went beyond identifying the NHS and the high-volume transportation facilities that connect to it. As a result, the concept of the NTS has undergone considerable revision and evolution. However, its basic mission has remained unchanged: to serve as the national-level mechanism for meeting the goals of ISTEA by supporting an integrated, intermodal, customer-oriented national transportation network. In order to do so, it must base its analysis on the multiple objectives of ISTEA: to serve the nation's mobility, environmental, social, and economic needs.

SPECIFICATION OF THE PROPOSED NTS

The NTS proposed in this report is designed to satisfy the federal government's needs for national transportation policy-making support in accordance with the mission of the ISTEA legislation. The following is an outline of the goals, objectives, and scope of this NTS.

Goals of the NTS

The following are the goals of the proposed NTS, the national priorities that transportation policy seeks to achieve:

1. Mobility: Provide adequate mobility for all users of the transportation network: passengers, freight carriers, and the armed forces and civil defense.
2. Connectivity: Provide a “robust” transportation network, in the sense that modal options and redundancies exist where needed, and facilitate transfer between links and modes.

3. Cost-Effectiveness: Minimize user costs and societal costs of the transportation system.
4. Energy Efficiency: Minimize energy costs of the transportation system, especially non-renewable and imported energy sources.
5. Air Quality: Minimize emissions of harmful pollutants attributable to the transportation system.
6. Resource Impact: Minimize degradation and destruction of natural resources attributable to the transportation system.
7. Noise Impact: Minimize the noise impact of the transportation system.
8. Safety: Minimize fatalities, injuries, and crimes attributable to the transportation system.
9. Accessibility: Provide adequate and timely accessibility for system users between their origins and destinations, residential, employment, social, commercial, and military.
10. Neighborhood Impact: Minimize adverse impact of the transportation system on neighborhood integrity.
11. Economic: Provide mobility for system users that supports employment, regional economic growth, and interregional trade.

Since the proposed NTS is outcome-oriented, the performance measures proposed in the following chapter are directly related to these goals.

Objectives of the NTS

The following are the objectives of the NTS, the policy mechanism by which the NTS uses the performance measures to achieve the above national goals:

1. To monitor the performance of the nation's transportation network and detect weaknesses and deficiencies.
2. To guide national transportation policy-making that addresses these problems.
3. To track changes in performance over time.
4. To aid state and local transportation planning.

These objectives are the basis for a decision-making framework that guides the setting of policy under the NTS. The mechanism by which these objectives serve the above goals is described in more detail in the chapter describing the NTS policy-making framework.

Scope of the NTS

Contrary to the DOT guidelines, the NTS proposed here is more detailed, and the data and performance measures supporting it are more disaggregate. In principle, the NTS includes the nation's entire transportation infrastructure. Clearly it would be impossible to gather and analyze data for the entire network. Therefore, the NTS will monitor the national network by tracking "major" transportation facilities, elements that impact transportation performance in a national sense. This comprises high volume facilities as well as regionally important components that may not be as "high volume" as facilities in other areas, and facilities that serve a unique function or need. The NTS will include such facilities as major highways, railways, airports, and intermodal terminals and connectors.

Smaller elements of the transportation network will not be ignored, however. Although such elements cannot be tracked individually by the NTS, they will be monitored in a more aggregate form. The NTS will therefore monitor such systems as a metropolitan area's transit system, a metropolitan area's network of arterial roadways, a state's system of rural collectors, or a state's system of minor general aviation airports.

Although an NTS of such a scope represents significant challenges in terms of data collection, data gathering, and analysis, certain technological developments should contribute to making such an NTS not only feasible, but a truly valuable tool for guiding national transportation policy. Chief among these developments are geographic information systems (GIS) and intelligent transportation systems (ITS) technologies. Their applicability to the NTS will be discussed in subsequent chapters.

SUMMARY

Since its inception in December 1993, the NTS concept has evolved from a fairly simple mapping of major transportation facilities to a more complex, performance analysis system. This report proposes an NTS that is a data-based analysis tool for guiding national transportation policy. The NTS is national in scope, and includes major transportation facilities in all modes, as well as more aggregated data on the smaller-scale components of the transportation system. Its objectives are to monitor the nation's transportation network and detect weaknesses; to inform national policy-making that addresses these problems; to track changes in performance over time; and to support state and local transportation planning. The NTS is designed to pursue national goals in the areas of mobility, connectivity, cost-effectiveness, energy efficiency, air quality, resource impact, noise impact, safety, accessibility, neighborhood impact, and economic impact. The performance measures proposed in the next chapter serve as the means for monitoring performance with respect to these goals.

CHAPTER 3. PERFORMANCE MEASURES FOR THE NTS

INTRODUCTION

Proposed performance measures are the key component of this report. They will be the basic tool that the NTS uses to pursue national transportation goals. In order to be useful for pursuing the goals of the NTS and ISTEA, these measures must be outcome-oriented, intermodal, and user-oriented. This chapter lists initially proposed measures for the NTS, then describes feedback from transportation professionals on the measures and lists revised measures. The implications of these measures for the various modes is also discussed.

REQUIREMENTS FOR SELECTING NTS PERFORMANCE MEASURES

The NTS performance measures should seek to track performance as directly as possible with respect to the national goals listed in the previous chapter. The performance measures must therefore track performance both for transportation system outputs, and for outcomes resulting from system use. Keeping the transportation network functioning well and enabling its users to move through the system effectively and efficiently are certainly important goals. These aspects of performance are tracked by measures of system output, manifested by mobility, connectivity, and cost-effectiveness.

In contrast, many national goals relate to consequences, or outcomes, of the use of the transportation system. These outcomes may be the positive economic or social results that transportation system users seek to achieve, such as enhanced economic development or timely and convenient connection of residential areas to employment centers by means of the transportation system. On the other hand, the goal may be to diminish the negative environmental, social, and economic outcomes of transportation system use. Such negative impacts include emissions of pollutants, degradation of neighborhoods by transportation facilities, or the economic costs of congestion.

The measures must therefore be outcome-oriented, addressing not only the transportation network output, but also the environmental, social, and economic objectives and impacts of system use. This requires performance measures that address varied criteria relating to the outcomes of transportation system use: energy efficiency, air quality, natural resource impacts, noise, accessibility, safety, neighborhood impact, employment effects, and economic development.

The performance evaluation of the NTS must be user-oriented, recognizing that the purpose of the transportation system is to get passengers and goods to their destinations, rather than to enable vehicles to cover miles. The basic philosophy behind the performance measures proposed here is to express measures of the above criteria in terms of the passengers and goods moved, that is, on a per-passenger-mile-traveled (per PMT) or on a per-ton-mile basis, regardless of the mode or combination of modes utilized.

The performance measures selected must therefore be intermodal. Ideally, these measures will be consistent enough between modes to allow meaningful comparison of performance between modes, and to allow intermodal trade-off analysis. In order to facilitate this, many of the performance measures have been specified as a function of passenger miles traveled (PMT), or ton-miles for freight. PMT and ton-miles are basic denominators, applicable to many measures and common to all transportation modes. Their use will facilitate intermodal comparison. Some of the measures for different facilities and modes will be consistent and fairly comparable, while others will not. Care must be taken to determine whether measures are consistent in intermodal analysis, and whether adjustments can be made to increase consistency and comparability.

A central issue in selecting performance measures for the NTS is the specificity and level of detail desired. This report recommends using a limited number of fairly general measures within each criterion. There are several reasons for this approach. First, it simplifies the tasks of collecting and adapting data from different sources and formats to the desired measures. This approach is also more suited to such an extensive network, the analysis of which embraces such broad objectives. Specifying detailed measures would be prohibitive in terms of data collection and analysis. Simple measures make this large task more manageable.

While fairly general, the measures selected can serve as indicators for the overall facility or system performance with respect to the criterion in question. They can also indicate whether a problem exists in that area. Although such general performance measures will likely not provide enough detailed information to suggest a solution, they can direct further investigation into the problem. These measures can therefore facilitate an evaluation that looks into more specific performance measures, and/or a more detailed, disaggregate network.

The level of detail of these measures will be relatively fine, corresponding to the scale of transportation elements to be monitored by the NTS. Relative to the national scale of the network being monitored, the components of the NTS are of a fairly small scale: they are "major" facilities and finely integrated modal systems. Examples of major facilities are interstate highway links, Class I rail links, major airports (either high-volume or regionally important), and major ports. The modal systems that are to be tracked by the NTS are elements of the nation's transportation network that cannot be considered discrete facilities. The components of these systems are too finely grained to track individually, but the aggregated system nonetheless merits monitoring by the NTS. Examples of such systems are an urban transit system, an aggregation of an urban area's major arterials, and an aggregation of an urban area's park and ride lots.

Because the level of detail of the measures is high, the use of simple and general measures is essential to gaining a broad enough perspective to facilitate national policy-making. This will allow aggregation of many of the measures, particularly those defined on a per PMT or per ton-mile basis. This will enable monitoring and analysis of broader functional and geographic segments of the network. Simple measures will also allow more flexibility for the NTS to adapt to new technology and changing transportation patterns.

Performance of transfers and connections between modes must be considered, since these are critical components of intermodal trips. Traditional, modally-based thinking has often marginalized intermodal connections, especially in the public, passenger transportation sector. In order to increase the efficiency of the transportation system, advantage must be taken of the inherent efficiencies of each mode, which means increasing intermodal trip-making. Intermodal connections are therefore very important, and must receive attention and consideration in any performance analysis. In light of the neglect of many intermodal connections, such as landside access to ports and airports, it is possible that many of the problems and bottlenecks in the system are at connection points.

Since transfer is essentially different from movement on a link, it must be measured differently. Instead of being expressed in terms of PMT or ton-miles of freight, connector performance must be expressed in terms of passengers transferred or tons of freight transferred. As a result, many measures will not be directly comparable with measures expressed in terms of PMT and ton-miles. For example, trip time is naturally consistent and additive between links and connectors, but link emissions will be expressed in terms of PMT or ton-miles, while connector emissions must be expressed in terms of passengers transferred or tons transferred. Performance measurements of different links and connectors of an intermodal trip will not typically be additive, and will not allow a composite measure of performance for the entire trip. But when assessment of their performance is based on the same goals and criteria, links in different modes can be connected with each other and with intermodal connection points to yield a picture of the performance of the whole trip.

Another consideration, which is closely related to data issues that must also be taken into account, is whether to select performance measures on a top-down or bottom-up basis. The top-down approach seeks to obtain the performance measures that are truly desired for the best possible analysis, without regard for the availability of data to support these measures. This approach risks leaving some of these measures unspecified for certain sectors of the system if the data is not available, or else incurring the expense of collecting that data. A bottom-up approach selects performance measures based on the available data. This can make more complete use of the data, but it can also result in different sets of specified measures, depending on the data that has been collected in different modes and different jurisdictions. Alternately, if a uniform set of measures is required, the bottom-up approach can result in a sparse, lowest-common-denominator set of performance measures.

This report takes a basically top-down approach. It identifies desired measures and recommends obtaining as much existing data as possible to support these measures. This data-gathering process will provide bottom-up feedback in terms of which measures are well-supported by existing data, and which are not. Based on this feedback, other data sources can be tapped, the required data can be collected through a specialized effort, or the measure can be abandoned if it is found to be truly unnecessary or untenable. However, care must be taken to keep the set of performance measures uniform and robust, while still minimizing new data collection efforts and expenditure.

Finally, these performance measures are divided into measures for passenger transportation and for freight transportation. These two functions are basically different, and must be considered separately. Some facilities and systems will be solely for passengers, such as a transit system or an urban passenger intermodal terminal. Others will be solely for freight, such as a container port or a railroad link that has no passenger service. Many facilities and systems, however, will have both passenger and freight usage, such as major highways and airports. Both the passenger performance and the freight performance of these facilities and systems must be considered.

Within these sets of performance measures, no hierarchy is established. The "bottom-line" measures within each performance criterion, those measures generally expressed as rates per PMT or per ton-mile, predominate within that criterion due to their relative conceptual simplicity and intermodal applicability. However, between criteria, no measures are specified as primary or secondary. This is due to the manner in which the measures are to be used. The measures will be used for system performance monitoring and for guiding national transportation policy in all modes. Therefore, the relative importance and weighting of the different measures will depend upon the policy goal and the mode or modes in question. These issues will be dealt with in more detail in the chapter concerning the policy-making framework.

PROPOSED NTS PERFORMANCE MEASURES

The following are measures for tracking performance of the transportation system with respect to the national goals listed in the previous chapter. An attempt has been made to cover all relevant criteria, and to develop "bottom-line" measures.

Table 3.1 Passenger-Related Measures, by Link

Outputs

Performance Measure	Data Required and/or Components of Measure	
Mobility		
V/C Ratio	Facility or System Volume	Facility or System Capacity
Trip Time	Vehicle Travel Time	Delay Time
Average Speed		
Facility/System Usage	Total Passenger Miles Traveled (PMT)	
Facility/System Output	Total Passengers / Hr	
Connectivity	Major Facilities, Systems, Connectors Served	
Cost-Effectiveness	(Costs - Benefits) / PMT	
	Costs: Capital (Construction, Veh)	Operating (Labor, Maint.)
	Benefits: Revenues (Fares, Tolls, Taxes, Fees)	

Outcomes

Performance Measure	Data Required and/or Components of Measure			
Environmental				
Energy Efficiency				
Energy Consumed	Vehicle Fuel	Energy Required for Operating, Maint., Constrn		
Energy Intensity	Energy Consumed / PMT			
Air Quality				
Total Emissions	Vehicle Emissions	Operations, Maint., Construction Emissions		
Emissions Rate	Total Emissions (CO, NOx, VOCs) / PMT			
Resource Impact	Resources Degraded or Destroyed	Haz. Mat. Impact		
	Cost of Environmental Remediation / PMT			
Noise Impact	Population w/in "X" Decibels for "Y" Hours / Day			
Social				
Safety				
Incident Rates	Accidents/PMT	Injuries/PMT	Fatalities/PMT	Crimes/PMT
Incident Cost	Incident Delay / PMT			
	Full Cost of Incidents / PMT			
Accessibility	Population w/in "X" Minutes of Facility / System Access			
	Employment, Commercial Land Uses w/in "Y" Minutes of Access			
	Popn w/in "Z" Minutes of Employment, Commercial Land Uses			
Neighborhood Impact	Population Affected or Displaced by Construction			
Economic				
Employment Impact	Jobs Supported / PMT			
Economic Impact	Change in GDP /PMT	Cost of Passenger Delay Time /PMT		

Table 3.2 Passenger-Related Measures, by Intermodal Connector

Outputs

Performance Measure	Data Required and/or Components of Measure
Mobility	
V/C Ratio	Facility Volume in Passengers Transferred; Facility Capacity
Intermodal Time	Transfer Time; Waiting / Delay Time
Facility Output	Total Passengers Transferred / Hr
Connectivity	Major Facilities and Systems Served
Cost-Effectiveness	(Costs - Benefits) / Passenger Transferred
	Costs: Capital (Construction); Operating (Labor, Maint.)
	Benefits: Revenues (Taxes, Fees)

Outcomes

Performance Measure	Data Required and/or Components of Measure
Environmental	
Energy Efficiency	
Energy Consumed	Energy Required for Operating, Maintenance, Construction
Energy Intensity	Energy Consumed / Passenger Transferred
Air Quality	
Total Emissions	Operations, Maintenance, Construction Emissions
Emissions Rate	Total Emissions (CO, NOx, VOCs) / Passenger Transferred
Resource Impact	Resources Degraded or Destroyed; Haz. Mat. Impact
	Cost of Environmental Remediation / Passenger Transferred
Noise Impact	Population w/in "X" Decibels for "Y" Hours / Day
Social	
Safety	
Incident Rates	Accidents/Pax Transferred; Injuries/Pax Transferred
	Fatalities/Pax Transferred; Crimes/Pax Transferred
Incident Cost	Incident Delay / Passenger Transferred
	Full Cost of Incidents / Passenger Transferred
Accessibility	Population w/in "X" Minutes of Facility Access
	Employment, Commercial Land Uses w/in "Y" Minutes of Access
	Population w/in "Z" Minutes of Employment, Commercial Land Uses
Neighborhood Impact	Population Affected or Displaced by Construction
Economic	
Employment Impact	Jobs Supported / Passenger Transferred
Economic Impact	Change in GDP / Passenger Transferred
	Cost of Passenger Delay Time / Passenger Transferred

Table 3.3 Freight-Related Measures, by Link

Outputs

Performance Measure	Data Required and/or Components of Measure
Mobility	
V/C Ratio	Freight Volume; Facility or System Capacity
Trip Time	Vehicle Travel Time; Delay Time
Average Speed	
Facility/System Usage	Total Ton-Miles
Facility/System Output	Total Tons / Hr
Connectivity	Major Freight Facilities, Systems, Connectors Served
Cost-Effectiveness	(Costs - Benefits) / Ton-Mile Costs: Capital (Construction, Veh) Operating (Labor, Maint.) Benefits: Revenues (Tolls, Taxes, Fees)

Outcomes

Performance Measure	Data Required and/or Components of Measure
Environmental	
Energy Efficiency	
Energy Consumed	Vehicle Fuel; Energy Required for Operating, Maint., Constrn
Energy Intensity	Energy Consumed / Ton-Mile
Air Quality	
Total Emissions	Vehicle Emissions; Operations, Maint., Constrn Emissions
Emissions Rate	Total Emissions (CO, NOx, VOCs) / Ton-Mile
Resource Impact	Resources Degraded or Destroyed; Haz. Mat. Impact Cost of Environmental Remediation / Ton-Mile
Noise Impact	Population w/in "X" Decibels for "Y" Hours / Day
Social	
Safety	
Incident Rates	Accidents / Ton-Mile; Injuries / Ton-Mile Fatalities / Ton-Mile; Crimes / Ton-Mile
Incident Cost	Incident Delay / Ton-Mile Full Cost of Incidents / Ton-Mile
Accessibility	Freight Users, Destinations w/in "X" Minutes of Facility Access
Neighborhood Impact	Population Affected or Displaced by Construction
Economic	
Employment Impact	Jobs Supported / Ton-Mile
Economic Impact	Change in GDP / Ton-Mile Cost of Freight Delay Time / Ton-Mile

Table 3.4 Freight-Related Measures, by Intermodal Connector

Outputs

Performance Measure	Data Required and/or Components of Measure	
Mobility		
V/C Ratio	Total Tons Transferred	Facility or System Capacity
Intermodal Time	Transfer Time	Waiting / Delay Time
Facility/System Output	Total Tons Transferred / Hr	
Connectivity	Major Freight Facilities, Systems, Connectors Served	
Cost-Effectiveness	(Costs - Benefits) / Ton Transferred	
	Costs: Capital (Construction)	Operating (Labor, Maint.)
	Benefits: Revenues (Taxes, Fees)	

Outcomes

Performance Measure	Data Required and/or Components of Measure	
Environmental		
Energy Efficiency		
Energy Consumed	Energy Required for Operating, Maintenance, Construction	
Energy Intensity	Energy Consumed / Ton Transferred	
Air Quality		
Total Emissions	Operations, Maintenance, Construction Emissions	
Emissions Rate	Total Emissions (CO, NOx, VOCs) / Ton Transferred	
Resource Impact	Resources Degraded or Destroyed	Haz. Mat. Impact
	Cost of Environmental Remediation / Ton Transferred	
Noise Impact	Population w/in "X" Decibels for "Y" Hours / Day	
Social		
Safety		
Incident Rates	Accidents / Ton Transferred	Injuries / Ton Transferred
	Fatalities / Ton Transferred	Crimes / Ton Transferred
Incident Cost	Incident Delay / Ton Transferred	
	Full Cost of Incidents / Ton Transferred	
Accessibility	Freight Users, Destinations w/in "X" Minutes of Facility	
Neighborhood Impact	Population Affected or Displaced by Construction	
Economic		
Employment Impact	Jobs Supported / Ton Transferred	
Economic Impact	Change in GDP/Ton Transferred	
	Cost of Delay Time/Ton Transferred	

DISCUSSION OF MEASURES AND MODAL IMPLICATIONS

A critical feature of these proposed measures is the fact that they are geared to tracking performance with respect to national goals for all modes. This is not to say that the measures will be exactly the same between different modes. On the contrary, many measures will have very different bases for assessment in different modes. For example, cost measures will mean different things for the highway mode, for which users provide their own cost-intensive vehicle, and transit modes, for which users pay a fee to share a provided vehicle. However, the designation of generic, intermodal measures gives a basis for intermodal comparison and analysis. The intermodal characteristics of the measures are discussed, as are the some specific modal implications.

Output Measures

Mobility. Mobility measures are relevant to all measures under consideration. One important indicator of mobility is a measure of facility or system utilization, as expressed by a ratio of usage volume to facility or system capacity. The modal characteristics of such a utilization ratio are listed in the table below.

Table 3.5 Modal Implications of a Volume-to-Capacity Ratio for Links

Mode	Description of Measure
Passenger	
Highway	Volumes: Traffic counts Capacity: Roadway capacity (e.g. *Highway Capacity Manual*)
Air Rail Water Transit	Volumes: Ridership Capacity: Passenger spaces, based on full equipment usage for route
Freight	
Highway	Volumes: Traffic counts Capacity: Roadway capacity (e.g. *Highway Capacity Manual*)
Air Rail Water	Volumes: Freight tonnage Capacity: Tonnage capacity, based on full equipment usage for route

In assessing transport link utilization in terms of some volume to capacity ratio, air, rail, water, and transit modes are similar, and quite different from highway modes. With highway modes, capacity is dependent upon physical and operational characteristics of the roadway, and users provide their own vehicles. Therefore, physical space and flow are important in determining the utilization of the roadway.

In the other modes, air, rail, water and transit, the operations of the vehicle fleet will generally not maximize the physical capacity of the right-of-way. Therefore, the critical path determining capacity is the capacity of the vehicle fleet. This capacity can be measured in terms of the passenger spaces available or tonnage capacity available when the vehicle fleet is at maximum operation. Volumes can be measured in terms of passenger ridership and tons of freight.

These utilization ratios must be determined for a specific point, or points, in time in order to delimit the facility or system volume and capacity. The point or points to be used must therefore be identified for each given facility or system, for passenger and freight. The most important point is a peak period for the facility. Defining the utilization upon a system's annual peak would exaggerate volumes experienced, so a more typical, habitual peak should be selected. A daily or perhaps weekly peak period should be selected, depending upon facility or system characteristics. For urban passenger facilities, this will be an AM or PM peak period. If possible, values for both peak periods and perhaps an off-peak period should be included.

For urban freight modes that share facilities or systems with passenger modes, such as in the case of an urban highway, the freight usage may be heaviest at times that are non-peaks in terms of overall volume. This may be due to truck drivers choosing to travel through urban areas at off-peak times in order to reduce congestion delay. These points should also be tracked for the freight mode, as well as for the overall peak periods. Other peak times will vary. For example, a rural highway in a resort area may experience peak travel on summer weekends at midday. Such effects should be taken into account when identifying peak times to monitor.

Intermodal connectors may also be assessed in terms of utilization. The considerations involved in such transfer point utilization differ from those involved in link assessment. The ways in which to measure the volumes and capacities of some of these connectors is summarized below.

Table 3.6 Implications of a Volume-to-Capacity Ratio for Intermodal Connectors

Mode	Description of Measure
Passenger	
Urban	Volumes: Passenger transfers
Intermodal	Capacity: Physical characteristics of terminal (adequate flow, waiting area)
Terminal	Vehicle handling capacity, by mode
Airport	
Park & Ride	Volumes: Cars parked
Airport Parking	Capacity: Parking spaces
Freight	
Port	Volumes: Tons transferred
Airport	Capacity: Equipment capacity
Truck-Rail	Freight storage space
	Vehicle handling capacity, by mode

These measures of intermodal connector utilization are also relevant to a specific point in time, and should be defined upon the facility's peak transfer time.

Other mobility measures are more straightforward. Average speed and trip time are directly collected for many facilities by such techniques as floating car studies. For intermodal connectors, transfer time and waiting / delay time can be determined through surveys or sample trips. These times are for direct time costs of the facility or system; related to these measures is accessibility, which is based upon the time required to get to and through the transportation network. The measures of accessibility are in some ways less concrete than the mobility time measures, but address the desired goals of the transportation network more directly, i.e. they are more outcome-oriented. These accessibility measures will be discussed in more detail below. The average speed and trip time measures are also specific to a point in time and should also be defined for the facility or system's peak period.

Total link usage is measured in terms of total PMT and total ton-miles. The bottom-line measures for mobility output of both links and connectors are passengers / hr and tons / hr. Such measures of output enable analysis of intermodal flows. These measures of output, along with the measures of volume / capacity utilization, should provide a useful means of assessing how passenger and freight flows move. They can also suggest alternative flows and intermodal trip options. These measures of total usage and output should be expressed for the peak period as well as for overall usage.

In general, other measures are either not explicitly dependent upon time of day or time of year, or these measures should be determined for overall usage.

Connectivity. The connectivity of the network is critical to its effective intermodal function. However, it is difficult to describe, especially in a quantitative manner. The first consideration is a catalogue of the connections between facilities, systems, and intermodal connectors. Such a linking of the physically connected components of the network is necessary in order for the analytical NTS to function. The NTS must be able to put together links and intermodal connectors to form multi-link and intermodal trips. To do so, it must recognize how the components are connected in reality. The issue of connectivity is addressed further in the chapter concerning GIS.

Cost-Effectiveness. A key measure of a transportation element's performance is its cost-effectiveness, in terms of the difference between financial costs and benefits per PMT or per ton-mile. These costs and benefits will vary widely from mode to mode, and there is also a wide variety of methods by which these costs and benefits can be calculated. Different methods will introduce different biases and produce different results. It is important to try to be as consistent as possible in making assumptions relating to financial matters. The following is a listing of various modal issues in measuring cost-effectiveness.

Table 3.7 Modal Implications of Financial Cost-Effectiveness

Mode	Description of Measure	
Passenger		
Highway	Costs:	Construction, maintenance, operation
	Benefits:	Tolls, user fees, fuel taxes
Air Rail Water Transit	Costs:	Construction, vehicles, maintenance, fuel, operation, labor
	Benefits:	Fares, fees
Freight		
Highway	Costs:	Construction, maintenance, operation
	Benefits:	Tolls, user fees, fuel taxes
Air Rail Water	Costs:	Construction, vehicles, maintenance, fuel, operation, labor
	Benefits:	Carrier fees

One key assumption is that only provider costs and benefits are considered; user costs and benefits are not. Therefore, private vehicle costs are not included in costs for the highway mode, nor are fuel costs for those private vehicles. However, these costs are considered in the case of air, rail, water, and transit modes, because the provider pays these costs.

Also important is the issue of capital costs, such as construction, vehicle purchase, and even land acquisition. These values seem out of place in an analytical system designed primarily for the monitoring of system status and for informing national policy-making. In the first place, such investment decisions are clearly the responsibility of states and MPOs in the vast majority of cases. In the second place, they represent "sunk" costs, and generally are not currently at issue in a decision-making sense. However, these costs represent investment in the transportation network, especially to the degree that they are not covered by the benefits of the component in question and must be subsidized. Such cost-effectiveness is an important element of the performance of a facility or system, and must be tracked. Capital costs and even sunk costs can be measured by determining the annualized cost of the land, construction, vehicles, and maintenance over the lifetime of each investment. This annual cost can be subtracted from the annual benefits and divided by annual PMT delivered to derive a measure of cost-effectiveness.

Another consideration is the assignment of costs of shared facilities. A notable example of this is highways shared by automobiles and trucks. Due to the greater wear exerted by the much heavier trucks, a reasonable model would assess the highway freight mode a higher relative share of the costs, at least of maintenance costs. Although such a structure would be politically sensitive with respect to freight carriers, it would be preferable to such alternative methods as weighting costs by VMT, or simply combining the costs and benefits of both automobiles and motor freight. The NTS should model reality to the degree practical, so that it will be useful in guiding transportation policy.

This measure of cost-effectiveness includes only direct monetary costs and revenues. Whenever possible, non-monetary costs and benefits are expressed in monetary terms and included in the set of proposed performance measures, but under other categories and goals. For example, costs of accidents, and fatalities are included under safety; economic and employment benefits as well as costs of delay are included under economic impacts; and costs of environmental remediation are found under natural resource impact.

The NTS tries to look at performance in as comprehensive a manner as possible, in this measure of cost-effectiveness and in other measures as well. This comprehensiveness is shown in the consideration of impacts of construction, maintenance, operations (operation and upkeep of non-right-of-way and non-vehicle facilities, such as terminals and stations, as well as such things as lighting and heat), and labor. In addition to costs, these items may also contribute to energy consumption, emissions, resource impact, and economic impact, among other things. Some of these items, such as operations and labor, are ongoing, are therefore suited to tracking over time, along with other factors contributing to the impacts. Construction and maintenance, however, have impacts that are more discrete in terms of time. Annualizing these impacts over the lifetime of the improvement would be somewhat inaccurate, and would be inappropriate for project programming. However, for the NTS, whose object is more macro-level planning and policy-making, annualizing impacts of construction and maintenance over their lifetimes would be an acceptable approximation.

Outcome Measures

Because they relate to non-transportation goals, outcome measures are for the most part more readily expressed and understood in an intermodal environment. Not that these measures are more easily gathered or determined. Many are difficult to obtain, difficult to measure, or difficult to assign to specific facilities or systems. Like the output measures, outcome measures are proposed as strictly quantitative. However, in some cases, reliable quantitative data may not be available. In these situations, qualitative measures should be substituted with caution. This is done with the understanding that either quantitative measures should be developed, or the qualitative measures should be implemented in such a way that they are useful and reliable for informing transportation policy.

Environmental: Energy Efficiency. Energy efficiency is of course a key concern of the NTS. Transportation is one of the largest energy consumers in the nation, and heavily reliant on imported oil. The measures proposed seek to assign a value for energy consumption discrete facilities and systems. Since most energy consumption data is in an aggregate form, this will prove difficult. However, improved models of energy consumption based upon vehicle volumes, operational characteristics, and delay should provide some basis for this measure.

The composition of fuel consumption will vary between modes. Energy for highway modes will be composed overwhelmingly of gasoline, but will include some amount of diesel and alternative fuels, as well as such operational energy consumption as electricity for lighting. Energy for air transportation is also primarily petroleum, but associated consumption for airports for lighting and heating will be relatively higher than associated consumption for highway modes. Energy for rail, water, and transit modes will vary depending upon the vehicle type and technology; these modes will also have higher associated operating energy demands than will highway modes.

Once data for fuel consumption have obtained, this measure has the advantage of consistency. Even though different modes use different fuel types and sources, it may all be reduced to a common measure, whether that be British thermal units (Btus) or a more familiar measure, such as gallon-of-oil equivalents. This energy consumption can be expressed in a per PMT, per passenger transferred, per ton-mile, or per ton transferred basis to give a bottom-line and fairly intermodal measure of energy intensity. Nonetheless, the type of fuel used is also important, and should be tracked as well.

Environmental: Emissions. Reduction of emissions is also an important goal of the NTS, especially in the air quality-conscious environment of ISTEA and CAAA. Emissions are closely related to energy consumption, and the two share some similar concerns. One of these concerns is assignment of aggregated emissions to specific facilities. Complex models can separate emissions into their component sources, both mobile and point source. The NTS must rely upon these models in order to assign emissions to major facilities and to aggregate systems.

The use of different energy sources by different modes results in emissions generated in different ways. Passenger and freight highway modes, and motor bus transit, generate emissions directly, as they travel. The exception to this is zero-emission vehicles (ZEVs), such as electric or hydrogen fuel cell vehicles. It is not true, however, that such vehicles have no emissions; their emissions are simply generated as a function of the fuel storage process, and are felt as the point source emissions of the power plant contributing the power. In a similar manner, the emissions from electric modes, such as heavy and light rail and electric transit bus, are generated by the power plants producing the electricity.

Air travel generates fossil fuel emissions, but much of this is in high-altitude and remote locations, where some emissions are not as critical a problem (although greenhouse gas CO2 is a problem here as well). Most intercity freight and passenger rail operates on diesel power, and thus generates mobile emissions. Operational emissions may be either directly-generated point source emissions, as in the case of fossil fuel heating, or indirectly-generated point source emissions, as with electrical power.

In addition, not all emissions have equal impact. Directly generated passenger automobile emissions for urban highways, where emissions are most critical, will be highest during peak commuting periods, while freight highway mode emissions will be highest at off-peak times. Electrical power emissions may be generated at remote locations, and can be generated off-peak. However, specific electrical power generation and emissions cannot be assigned directly to its transportation uses, as distinct from its other uses. All of these factors present challenges for modeling of facility and system-based assignment of emissions. Once assigned, albeit roughly, to a facility or system, emissions can be expressed as a per PMT, per passenger transferred, per ton-mile, or per ton transferred rate.

Environmental: Natural Resources Impact. For the most part, the natural resource impact of transportation facilities will be a one-time phenomenon. This might be in terms of wetlands destroyed in construction of a transportation facility. The impacts may also be felt as wetlands or other resources continually degraded by such transportation effects as salt run-off from roadways or transportation noise that has resulted in abandonment of an area by wildlife. Natural resource impacts are also felt in terms of the effects of hazardous materials due to transportation facilities and systems. Such impacts must be expressed in a fairly qualitative manner. They can also be expressed more quantitatively, as a function of the estimated cost of remediation per PMT, per passenger transferred, per ton-mile, or per ton transferred. Even if remediation is not undertaken, this measure will serve as an indicator of natural resource impact. However, in some cases, such remediation will not be possible, especially in the case of destroyed resources. In such situations, this quantitative cost measure will not be possible.

Environmental: Noise Impact. Another environmental impact is that felt due to transportation facility and system noise. This can be measured in terms of population exposed to some unacceptable decibel level for more than a certain amount of time per day. The development of GIS will aid in the implementation of this measure.

Social: Safety. The measures of safety are relatively straightforward. They call for the tracking of accidents, injuries, fatalities, and crimes for links and connectors. The value of such measures is widely accepted, and most of this data is already collected. Expressed as a per PMT, per passenger transferred, per ton-mile, or per ton transferred rate gives these measures intermodal application and comparability.

Also included under safety are measures of the costs of these various incidents. These costs are the delay time attributable to these incidents, as well as in terms of full financial costs due to the incidents. These costs are also expressed as a per PMT, per passenger transferred, per ton-mile, or per ton transferred rate.

Social: Accessibility. Accessibility is an important measure of the social goals of the transportation network in terms of providing mobility for its users. The use of GIS is integral to the facilitation of such a measure. The measures of accessibility proposed here are facility- or system-specific measures. That is, they describe accessibility based upon accessibility to a facility or system. For passengers, this can be accessibility of residential population to the facility or system in question, or else the accessibility of employment or commercial land uses to the facility or system. For freight modes, it is accessibility of a freight user or freight destination to the facility or system.

The measurement of accessibility can also be based upon accessibility to some destination by way of the facility or system. This is a more outcome-oriented measure than accessibility to the transportation network itself. This is more relevant to passenger modes. For this, the accessibility of residential population to employment or commercial land uses can be measured, or vice-versa. Such a measure is not as applicable to freight modes, for which it is more difficult to separate origins from destinations. For example, an manufacturing plant will be both an origin, for finished goods, and a destination, for raw materials.

There are also non-facility or system specific measures of accessibility. These will resemble the measures identified here, but will tend to be expressed in percentages, such as "% of population within 'X' minutes of employment centers of 'Y' or more jobs," or "% of businesses of '$ A' sales per year within 'B' minutes of a Class I railroad." These measures should be able to be derived from the data on an NTS GIS, or may require some supplementary GIS data.

These measures of accessibility are also proposed in terms of time, i.e. "Origin within 'X' minutes of destination." Accessibility could also be measured in terms of distance, i.e. "Origin within 'X' miles of destination." Such a distance-based measure would be more easily developed, since a time-based measure of accessibility must be derived from distance and average speed on a given facility or system. However, distances can mean different things for different modes and classes of facilities. Therefore, time is a more user-oriented and intermodal measure of accessibility than distance alone would.

Social: Neighborhood Impact. Neighborhood impact is similar to natural resources impact in that it is a one-time impact. It may be manifested as the population, or other land use, displaced by construction. It may also be manifested as a continuous impact, in terms of the population or other land uses exposed to adverse conditions due to the presence of a transportation facility. Although it can be expressed quantitatively, in terms of a number of residents or number of businesses impacted, this measure is also fairly qualitative and even subjective. It requires the definition of such things as what constitutes adverse conditions in situations short of displacement. This measure also addresses issues of social equity in transportation policy and decision-making.

Economic: Employment & Economic Impacts. The employment and economic impacts of the transportation network on the surrounding economy are naturally very important goal areas. These measures are most easily derived based on the costs of transportation and some employment and economic multiplier factors. As with the financial costs of the transportation elements, the derivation of these measures is more straightforward for ongoing costs, such as operation and labor. For more discrete investments like construction, maintenance, and vehicle costs, the employment and economic impacts are felt over a limited time, although they will have residual effects due to corollary economic activity generated by these investments. These employment and economic impacts can also be annualized; this would give a misleading picture of a local economy, but would be appropriate for more aggregate monitoring activities.

Another economic impact, but one of a negative nature, is the cost to the economy of congestion and delay. Such costs are felt in the passenger sector primarily as lost productivity due to delayed workers. They are felt on the freight side as lost productivity due to delayed raw materials, lost competitive advantage due to delayed delivery of a finished product, greater shipping costs due to increased time in transit, and increased carrying costs due to delayed pick-up or delayed delivery of materials needed to process the stored commodity.

All of these impacts can be expressed intermodally in terms of dollar impact per PMT, per passenger transferred, per ton-mile, or per ton transferred.

SUMMARY

The NTS performance measures proposed in this chapter were selected in accordance with the goals of the NTS and the spirit of ISTEA. Therefore, these measures are intermodal, outcome-oriented, user-oriented, and designed to measure performance with respect to the goal areas of mobility, connectivity, cost-effectiveness, energy efficiency, air quality, noise impact, safety, accessibility, neighborhood impact, and economic impact. Although these measures are proposed in a mode-neutral manner, the implications of using these measures with different modes must be addressed. These implications are especially important for gathering data to support the measures and for making intermodal trade-offs in using the NTS to support national policy-making.

CHAPTER 4. DATA REQUIREMENTS

INTRODUCTION

The NTS must be able to measure the performance of specific components of the nation's transportation network. This requires a great deal of data relating to the various mobility, environmental, social, and economic criteria that have been identified. The NTS must also be able to aggregate performance measures to give a broader regional and national picture of performance, and to evaluate trade-off between modes and criteria. This requires data that are consistent, especially within modes. However, among modes these data should also be consistent enough to allow meaningful comparison among modes within in corridor, or in combination in an intermodal trip. This chapter identifies the requirements for data to support an NTS database and sources of data that may be useful in constructing it. A small sample of data from urbanized areas in the central Texas region is obtained to demonstrate the applicability of existing data to the proposed measures. This demonstration and the problems encountered are discussed.

REQUIREMENTS FOR DATA TO SUPPORT THE NTS

A tremendous volume of transportation data is currently collected and stored, at all levels of government. Since it is naturally desirable to minimize NTS cost, it should rely upon data that is already collected. Even using existing databases will be expensive for a project as large as the nation's transportation network, so DOT must try to achieve whatever economies are possible. It should attempt to achieve economies of scale by tapping the largest and most comprehensive databases. However, even more important is the form of the data: the less conversion and cleaning of data is required to adapt it to the NTS performance measures, the more easily and cheaply the NTS database can be built.

Early in its implementation, the scope and completeness of the NTS database will be limited largely by availability of data in a useful format. Although the same general measures will be applied nationally, in many cases the NTS will have to rely on state and local data that are inconsistent in terms of format, coverage, and detail. However, greater national uniformity of transportation data collected on all levels is a desirable goal. The ISTEA-mandated state transportation management systems require states to base their transportation planning on the same broad criteria, which will encourage greater data consistency between states and metropolitan areas. This uniformity will also be aided by developing technologies, one of the most important of which is GIS, which will be discussed in detail in a subsequent chapter.

The NTS can encourage greater uniformity of data and performance measures by identifying general performance measures that are applicable nationally. Again, this uniformity of data and performance measures should not be looked upon as an occasion for comparison between states, but as an opportunity for more effective planning, both nationally and at the state and local level. This data can be supplemented by any new national data collection efforts required to fully meet the needs of the NTS.

The data for the NTS must be at a fairly detailed level: it must be available at the facility level for "major" transportation facilities. The nature of these facilities has been discussed in the chapter on performance measures. This chapter will deal with the implications this scale of data has for collecting data, which sources can provide data at the necessary level of detail, and what form it will take.

Due to the diverse goals of ISTEA, the data required for NTS analysis is diverse as well. Data is needed to assess not only system outputs, but also environmental, social, and economic outcomes. In order to capture data for all of these criteria, it will be necessary to search for data not only at various governmental levels, but also with agencies aside from traditional transportation agencies, such as environmental and energy agencies, economic and labor agencies, public safety agencies, and others. Data from the private sector, especially for freight measures, is also desirable, although it will often be quite difficult to obtain. Some measures may require new data collection efforts tailored to the NTS initiative.

For the demonstration of data procurement, data was sought and obtained for the central Texas region comprising Austin, Dallas - Fort Worth, Houston-Galveston, San Antonio, and the links connecting the cities. The discussion of data sources below is specific with respect to national data sources, but must be generic when discussing state and local sources since the level of data collection and analysis will vary between different states, MPOs, and localities. On the state, MPO, and local levels, discussion of data sources is influenced by experiences with the Texas Department of Transportation, Texas Natural Resources Conservation Commission (TNRCC), Texas Department of Public Safety (DPS), other Texas state agencies, MPOs of the cities in question, and other local agencies. Information on the national data sources is based largely upon *Directory of Transportation Data Sources, 1995,* Bureau of Transportation Statistics (BTS), DOT.

DATA SOURCES FOR THE NTS

The following are candidate data sources for supporting the NTS performance measures. There will be overlapping data, as well as gaps between what the data can provide and what the performance measures require. There will be other applicable data sources that this report has neglected. Furthermore, there will be variation in the data available from different states, and probably even greater variation in the data available from MPOs, municipalities, and other local agencies.

The following data sources are broken down by mode. They are also broken down by criterion and passenger vs. freight to the degree that is appropriate, considering that some databases are applicable to various criteria, and to both passenger and freight usage. The data sources below contain information other than that cited here; the information cited here is that which is applicable to the NTS performance measures.

Highway Mode

- Mobility: Volumes and Capacity: Highway Performance Monitoring System (HPMS): Federal Highway Administration (FHWA): Provides basic roadway characteristics (including link length and functional class) for the entire public roadway system, and more detailed data relating to mobility (AADT, peak hour volume, vehicle occupancy, peak hour capacity), safety (total accidents, fatalities, injuries), and other characteristics for a sampling of the system. Data is available for various vehicle types, and can be broken down by passenger vs. freight. This sampled data is used to develop areawide statistics. The sample data is useful for describing the performance of major principal arterials under the NTS, and the areawide data is applicable to describing the aggregated performance of the other principal arterials and minor arterials in an urban area. However, additional data may be needed to capture performance of discrete major principal arterials that are not sampled under the HPMS. States DOTs, with MPO support, provide these data to FHWA. Supplementary sources for highway passenger data include the Nationwide Personal Transportation Survey (NPTS), maintained by the FHWA, and the American Travel Survey, kept by the Bureau of Transportation Statistics (BTS). Each of these databases contains sampled survey information of household trip-making patterns, and both are multimodal. Information on freight mobility is available through the Commodity Flow Survey (CFS), collected by the Bureau of Census, Department of Commerce. The CFS provides information on shipment origin and destination, weight, value, commodity, and transportation modes used. The CFS is also multimodal, and provides data not only for the highway mode, but also air, rail, and water.

- Mobility and Connectivity: National Highway Planning Network Version 2.0 (NHPN - V2.0): FHWA: GIS database of major highways in the U.S. The NHPN includes such attributes as route designation, functional classification, number of lanes, type of access control, and median type. The NHPN would also address connectivity issues for the highway mode. An FHWA project is underway to add HPMS data to the NHPN, which would create a GIS database that could form the basis of an NTS GIS database for the highway mode.
- Mobility: Volumes, Travel Times and Speeds: MPO or Local Congestion Management Initiatives: In response to ISTEA requirements for congestion management systems and in order to address congestion in general, MPOs and local transportation planning entities may track volumes, travel times and speeds for urban area expressways and arterials. This data can also support measures of delay times and economic impacts of congestion and congestion relief from construction or rehabilitation.
- Cost-Effectiveness: State DOT Project Programming and Costing Data: Most major highway construction, rehabilitation, and maintenance projects will be conducted under state or local authority. Project data, including facility, system, cost, and scope of work should be available from state DOTs or local planning authorities or departments of public works. The Texas Department of Transportation (TxDOT) plans to put this data in a GIS format, which would facilitate assignment of costs to facilities and systems under the NTS. Information on revenues from tolls, taxes and user fees should also be available from state DOTs.
- Energy Consumption: Data on energy consumption is not available for the link level, nor is it feasible to collect this data directly. This information is available on more aggregate levels: national, through the Department of Energy (DOE); at a state level, through the state DOTs or state environmental agencies; and sometimes regionally or for urbanized areas, through MPOs or local planning entities. Fuel consumption models can be used to assign energy use to facilities based on volumes, travel speed, congestion, delay, and fuel efficiency by vehicle class. However, these models should be based on the most disaggregate and detailed available, since highly aggregated data will produce inaccurate measures.
- Emissions: As with energy consumption, direct facility-level data will not be available for emissions. However, under the CAAA, regional emissions must be tracked for each National Ambient Air Quality Standards (NAAQS) area, an area which generally

includes each major urbanized area. This data will be collected locally and regionally, and should also be available from state environmental agencies. Emissions models can be used to assign emissions to facilities based on volumes, fuel consumption, congestion and other factors. These measures, and the facility measures for energy consumption, will be accurate only to the degree that the aggregate values are accurate and to the degree that the models used represent the actual energy consumed and emissions generated. The measures for emissions are complicated by the fact that a large proportion of highway-related emissions are generated in vehicle start-up. As a result, some emissions can be assigned to NTS facilities on the basis of emissions models, but most emissions must be expressed in a more aggregate manner, over a given area.

- Natural Resources Impact and Noise Impact: Environmental Impact Statements (EISs) of state DOTs and local transportation authorities. The EISs should describe the natural resource impacts and noise impacts of construction, rehabilitation, maintenance, and operation of highway facilities and systems. This data can sometimes be supplemented by state, county, and local environmental monitoring.
- Safety: A great deal of highway safety data is already collected. Some is aggregated at the national level, as with the Fatal Accident Reporting System (FARS) kept by the National Highway Traffic Safety Administration (NHTSA) at DOT, or the Motor Carrier Accidents database kept by FHWA. However, all of this data comes from the state level. It is therefore best to obtain this data from the states, usually the state police or state public safety agency. Such data is currently aggregated by region, but incidents will be identified as to the facility, system, and location where they occurred. Based on this detailed geographic information, safety data can be assigned to facilities and systems in an NTS GIS database.
- Accessibility: Geographic highway data: National Transportation Atlas Data Bases, including the National Highway Planning Network (NHPN). Geographic land use data: Bureau of the Census, Department of Commerce. Accessibility measures are clearly very reliant upon GIS capability. Measurement of highway accessibility requires that the NTS highway network be linked to geographic data on population, employment, commercial facility, freight terminal and freight destination data. Information on population, employment location and journey-to-work trip-making is available through the Census of Population and Housing. Information on freight destinations and flows

is available through the Census of Manufactures, Commodity Flow Survey, and Motor Freight Transportation and Warehousing Survey.

- Neighborhood Impact: Information on neighborhood impact of highway construction, rehabilitation, maintenance, and operation should be available from state DOTs and local transportation programmers executing the transportation system improvements leading to these impacts.
- Employment Impact: Bureau of the Census, Department of Commerce. Employment impact will be felt in different ways. Direct highway facility- and system-dependent employment will arise out of construction, rehabilitation, and maintenance work on the NTS roadway components. Information on this employment can be obtained through the state and local transportation entities that provide information on the transportation facility and system financial costs. Other highway system employment impacts are felt through employment in transportation-related industries that rely upon the highway network, such as motor freight and intercity bus. These impacts can be assigned to transportation facilities and systems based upon the degree to which these transportation services uses specific facilities and systems. Information on the employment impacts of these services can be obtained from the Bureau of the Census' Census of Transportation, Communications and Utilities subject series. Regionally appropriate employment multiplier factors should be applied to the employment impact measures.
- Economic Impact: Bureau of the Census, Department of Commerce. Economic impacts of direct spending upon the roadway system can be determined with system cost data from state and local sources, along with economic multiplier effects. Economic impacts of spending on transportation services can be determined using data from the Bureau of the Census' Census of Transportation, Communications and Utilities subject series.

Air Mode

- Mobility: Volume and Capacity: Air Carrier Activity Information System (ACAIS), Airport Activity Statistics of Certificated Route Air Carriers, Office of Airline Information (OAI) Passenger Ticket Sample: Federal Aviation Administration (FAA). These sources contain volume information on passenger enplanements freight and mail revenue ton enplanements by airports for all U.S. airports. They also contain capacity information in the form of passenger and freight operations by airport according to type of aircraft. Based upon the passenger and/or freight capacity of these aircraft, a volume-to-capacity ratio of passenger and freight enplanement could be determined. This addresses mobility issues for the airport connectors. The OAI tracks detailed airway link information through a 10% sample of passenger tickets. Data on freight link movement may be obtained from the CFS.

- Mobility: Delay, Speed, Travel Time: Air Traffic Operating Management System, FAA and On-Time Performance Monitoring System, Research and Special Programs Administration (RSPA). These sources contain information on on-time performance and delay of aircraft by airport. This aids in determination of overall air travel times. Also necessary for determination of air travel times are aircraft speeds, inter-airport travel speeds, inter-airport distances, and in-airport transfer and delay times.
- Connectivity: National Transportation Atlas Databases: BTS. This GIS database contains locational information on airports, as well as on the national highway network and on transit and commuter rail systems. Linkages between these facilities and airports will provide information on landside access to airports. The FAA also maintains information on which airports are served by non-stop flights from other airports, which determines the inter-airport connectivity of the airway system.
- Cost-Effectiveness: Connector (airport) costs due to construction, rehabilitation, maintenance, and operation and revenues from user fees should be obtained from the airport owner, which will often be the locality in which the airport is located, especially for large high-volume airports. Since air links have no physical infrastructure, links costs will be attributable to vehicle and operating costs of the air carriers, and revenues due to passenger fares and shipping revenues. The Aviation and Data Analysis System (ADA) database maintained by the FAA, which provides cost/benefit information on changes in airport operations and use, should also be helpful in developing measures of air mode cost-effectiveness. The FAA's National Plan of Integrated Airport Systems and Capital Improvement Program (NPIAS - CIP) forecasts needed airport improvements and proposes funding allocation to meet these needs.
- Energy Consumption: The Department of Energy (DOE) tracks data on energy use per PMT and per ton-mile of freight, aggregated over the U.S. Such statistics could be used to give some measure of air mode energy use, although it would be imprecise. More accurate energy use measures could be determined from FAA data on inter-airport aircraft flows and energy consumption of these aircraft. Again, the

most disaggregate information available should be used. Airport operations energy use should be obtained from airport owners / operators.

- Emissions: Measures of emissions should be based upon the energy use figures determined from the sources above, and upon measures of emissions for NAAQS areas and the contribution of air travel to these emissions. Emissions models are generally concerned only with airport operations emissions, and aircraft take-off and landing emissions; airborne emissions above a certain altitude are not considered.
- Natural Resources Impact and Noise Impact: EISs of airport owners; state, county and local environmental monitoring.
- Safety: FAA Safety Statistics. The FAA tracks aircraft accidents and safety-related airport and aircraft incidents, including hijackings, explosions, and situations compromising air mode safety. This information can be assigned to airport connectors and airway links.
- Accessibility: Transportation network data: National Transportation Atlas Databases: BTS. Land use data: Bureau of the Census, Department of Commerce. These GIS databases can be used to determine accessibility of passenger and freight users to airports. These measures, along with measures of air travel times, can give information on accessibility of users to their final destinations.
- Neighborhood Impact: Information on neighborhood impacts due to airport construction, improvement, and operation should be available from airport owners and operators.
- Employment Impact: Airway Links: Comprehensive Airmen Information System, U.S. Civil Airmen Statistics: FAA. Airport Connectors: Employment statistics of airport owners and operators. The FAA tracks all aircraft personnel. This data, along with inter-airport aircraft volumes, could be used to generate employment impact measures for inter-airport links. For airport connectors, these measures can be derived from data on employment of workers required to operate the airport, including airport personnel as well as airport-based air carrier personnel.
- Economic Impact: The economic impact of the airway links can be determined based upon vehicle, operating, and labor costs, used in conjunction with appropriate economic multipliers. Similarly, the economic impact of the airport connectors can be determined from spending upon capital improvements, operations, and labor, along with economic multipliers.

Rail Mode: Freight

- Mobility: Volume and Capacity: Carload Waybill Sample: Federal Railroad Administration (FRA) and BTS. This database is a sample of rail shipments that includes origin and destination information, as well as volume data in the form of tons and type of commodity. Measures of capacity can be determined from the number of rail cars, the hauling capability of the train engines used in the shipment, and the level of traffic on given rail lines. This data can be supplemented with data from the Commodity Flow Survey (CFS) maintained by the Bureau of the Census.
- Mobility: Speed, Travel Time, Delay Time: Travel time measures should be able to be determined from length of haul data available from the Carload Waybill Sample and some measure of average travel speed. Delay time will depend upon railroad traffic and upon transfer time at rail freight terminals and intermodal terminals. This data may be available from freight carriers.
- Connectivity: National Transportation Atlas Databases: BTS. This GIS database contains locational information on the national railway network, as well as on major rail / highway intermodal terminals.
- Cost-Effectiveness: Carload Waybill Sample: FRA, BTS. This data sample also contains information on shipment revenue and estimated shipment cost based on the Uniform Railroad Cost System (URCS) developed by the Interstate Commerce Commission (ICC).
- Energy Consumption: Department of Energy (DOE). Measures of energy use by rail freight link can be determined based on ton-mile volumes from the Carload Waybill Sample and CFS, and from DOE statistics on energy use by ton-mile. More disaggregate data might be available from freight carriers, although many would likely be reluctant to provide this data. Connector energy use for freight terminals should be based upon sampling of the terminals themselves for operating energy use.
- Emissions: Rail freight will make up a relatively small proportion of overall regional emissions. Estimates of emissions by link and connector should be based upon energy use and expected emissions for that type of fuel.
- Natural Resource Impact, Noise Impact: Measures of these impacts should be based on any EISs that are available, as well as upon geographic data on the national railway network and on sensitive natural areas. For noise impacts, the geographic data must also be used to examine the relationship between the railway network and surrounding man-made land uses.

- Safety: Railroad Accident / Incident Reporting System (RAIRS), Grade Crossing Inventory System (GCIS): FRA. The RAIRS tracks all railroad-related accidents and incidents, both freight and passenger. The GCIS tracks all railroad grade crossings, which are major points of railroad safety concern, and the accident history of each one.
- Accessibility: Transportation network data: National Transportation Atlas Databases: BTS. Land use data: Bureau of the Census, Department of Commerce. These GIS databases can be used to determine accessibility of rail freight users to terminals. These measures, along with measures of rail travel times, can give information on accessibility of users to their final destinations.
- Neighborhood Impact: Impact of railway and terminal capital improvement and operation should be available from the rail carriers owning the rights-of-way, and from the owners or operators of rail terminals.
- Employment and Economic Impact: Data on freight rail employment and spending will be maintained by the rail carrier and rail terminal owners and operators. This data may be difficult or impossible to obtain, however, due to proprietary concerns.

Rail Mode: Passenger

The National Railroad Passenger Corporation (Amtrak), a private transportation agency, provides all intercity passenger rail transportation (urban and commuter rail is considered under the "Transit" mode). Data supporting all measures must therefore be obtained from Amtrak. Exceptions to this include safety data, which is also maintained by the FRA in the RAIRS database, and measures of connectivity and accessibility, which can be determined from the GIS databases of the National Transportation Atlas Databases (BTS) and the Bureau of the Census, Department of Commerce.

Water Mode: Freight

- Mobility: Volume and Capacity: Waterway volumes: Waterborne Commerce of the United States: U.S. Army Corps of Engineers (U.S. Army COE). Includes data on tonnage and commodity by waterway. Additional waterway volume information may be obtained from the Commodity Flow Survey (CFS). Waterway capacities: Exposure Data Base: U.S. Coast Guard (USCG). This database includes information on waterway traffic by vessel type and gross tonnage. Additional waterway capacity data can be obtained from the Intermodal Equipment Inventory maintained by the Maritime Administration (MARAD), DOT, which includes limited capacity information in the area of intermodal vessel capacities. Port volumes: Tonnage for Selected U.S. Ports: U.S. Army COE. Includes data on tons of cargo handled at major ports by domestic cargo, foreign cargo, and total cargo. Port capacities: Port Facilities Inventory: MARAD. Includes information on physical dimensions, berthing capacities, and cargo handling equipment and capacities by port.

- Mobility: Speed, Travel Time, Delay Time: These measures should be determined based on average vessel speeds, port congestion and waiting times for vessels, and transfer time and delay involved in transfer of cargo. This data should be obtained from water carriers and port operators.
- Connectivity: Connectivity within U.S. waterway network: National Transportation Atlas Databases waterway data, BTS, based upon U.S. Army COE GIS databases of waterway, port, and lock information. Connectivity of U.S. waterway network to the rest of the rest of the transportation network: National Transportation Atlas Databases, BTS, and Landside Access to U.S. Ports: DOT. This report addresses access problems facing ports: physical, land use, regulatory, and institutional.
- Cost-Effectiveness: Water carrier labor costs: Maritime Contract Impact System: MARAD. Calculates labor costs of ship operators. Capital and other operating costs and revenues for waterways and ports will be maintained by water carriers and port operators. They may be difficult or impossible to obtain, or may be obtainable only in a highly aggregate format. If possible, waterway and port volumes and capacities should be used to allocate costs and revenues for water freight shipment.
- Energy Consumption: Department of Energy (DOE). Measures of energy use by waterway can be determined based on ton-mile volumes from the Waterborne Commerce of the United States database and CFS, and from DOE statistics on energy use by ton-mile. Connector energy use for ports should be based upon sampling of the ports themselves for operating energy use.
- Emissions: Estimates of emissions by waterway and port should be based upon energy use and expected emissions for that type of fuel.
- Natural Resource Impact: Impact due to port construction, improvement, and operation: EISs by port owner or operator. Impact due to hazardous material spill or other incident: USCG Pollution Data Base. This database tracks pollution incidents. Useful in determining the actual impacts resulting from such an incident is the Hazardous Assessment Computer System (HACS), which models the events and details surrounding a pollution incident.

- Noise Impact: Transportation network data: National Transportation Atlas Databases: BTS. Land use data: Bureau of the Census, Department of Commerce. These GIS databases can be used to determine noise impacts of port operations on surrounding land uses.
- Safety: Marine Safety Information System: USCG. This database tracks all USCG involvement with merchant vessels including boardings, violations, and casualties.
- Accessibility: Transportation network data: National Transportation Atlas Databases waterway data, BTS, based upon U.S. Army COE GIS databases of waterway, port, and lock information. Land use data: Bureau of the Census, Department of Commerce. These GIS databases can be used to determine accessibility of water freight users to terminals. These measures, along with measures of waterway travel times, can give information on accessibility of users to their final destinations.
- Neighborhood Impact: Impact of port capital improvement and operation should be available from the port owners or operators.
- Employment Impact: U.S. Merchant Marine Data Sheet: MARAD. This report includes employment data for sea-going employees by vessel type, as well as employment port employment for longshoremen and shipyard employees.
- Economic Impact: Data on water carrier and port spending and economic impacts will be maintained by the water carriers and port owners or operators. This data may be difficult or impossible to obtain, however, due to proprietary concerns.
- Fishing vessels cannot be considered freight vessels in a strict sense, since they do not perform an origin-to-destination transport function. As a result, many performance measures, such as those expressed in terms of ton-miles, will be inapplicable to fishing vessels. Nonetheless, their performance should be monitored.

Water Mode: Passenger

- Not all measures are relevant to the passenger water mode. Ferry traffic is covered under the "Transit" mode. Most remaining passenger water traffic is pleasure boating, for which most output measures are not relevant. Outcome measures are more relevant, especially measures of impacts, such as energy consumption, natural resource impact, and safety. Output and outcome measures may also be considered for passenger cruise ships, since these do generally serve an origin-to-destination transport function.

Transit Mode

All data to support the performance measures for the transit mode is generally available through the Federal Transit Administration's (FTA) Section 15 Reporting System. The following data is available through Section 15:

• Mobility:	Passenger trips
	Passenger miles traveled (PMT)
	Vehicles operated during peak hour
	Revenue vehicle miles
	Revenue vehicle hours
• Cost-Effectiveness:	Capital costs
	Operating expenses, by purpose
	Operating funds, by source
• Energy Consumption:	Fuel type
	Fuel consumed
• Safety:	Incidents, accidents, and fatalities
• Employment Impact:	Employees
	Labor costs

Other sources of transit data:

- Connectivity: National Transportation Atlas Databases, BTS. This GIS database includes transit networks and terminals.
- Accessibility: Transit network: National Transportation Atlas Databases, BTS. Land use data: Land use data: Bureau of the Census, Department of Commerce. These GIS databases can be used to determine accessibility of passenger to the transit system and to their destinations.
- Emissions: Can be determined based upon fuel type and consumption. Information on NAAQS area emissions and transit routing may also be helpful.
- Natural Resource Impact: Can be determined from EISs of transit agency, if applicable.
- Noise Impact: Can be determined from network and land use GIS databases.
- Economic Impact: Can be determined from capital, operating, and labor expenditures. Transit economic impact should also be considered in the sense of creating or sustaining commercial corridors or zones surrounding transit routes and terminals. Network and land use GIS databases can help inform such measures.

ADAPTATION OF SAMPLE DATA TO PERFORMANCE MEASURES

In order to demonstrate the applicability of existing data to the proposed performance measures, and to show some of the difficulties involved in doing so, a limited sample of data was obtained and adapted to the performance measures. Data was obtained for the central Texas region, for the urbanized areas of Dallas - Fort Worth, Houston - Galveston, San Antonio, and Austin. Sources include federal, state, and local agencies, and correspond to the potential sources cited above. Specific sources are listed after each data table.

Attempts were made to obtain data for as many modes as possible, and for as many of the proposed measures as possible. If the data available was not sufficiently disaggregate, more aggregate data was used. However, only data aggregated up to the level of counties or urbanized areas was used; state and national data was not used, since it was felt that such data would prove too aggregate to be accurate. However, it may be necessary to use highly aggregated data, such as national figures for energy consumption or emissions, at least early on in NTS implementation, until more reliable regional data is available.

In general, difficulties arose in obtaining data at a sufficiently disaggregate level, especially for outcome data. Much of this data exists in an appropriately detailed form, but could not be obtained. For example, data on highway accidents is geographically specific, and can be attached to a highway link; however, the agency with the data, the Texas Department of Public Safety (DPS), could not provide it in this format. As a result, data on roadway accidents, fatalities and injuries is only presented for overall urbanized areas.

For the NTS, outcome data aggregated over urbanized areas is desirable, but link-level data should also be included for the major facilities that the NTS will track directly. Output measures, especially mobility, were somewhat more readily available, but this was dependent upon the specific mode and facility.

The data and measures listed below are not in the exact form prescribed in the proposed performance measures. This is due to data limitations, and the need to use let some available data serve as a proxy for desired data.

Highway Data

Table 4.1 Austin Highways - IH 35

South *North*	Wm Cannon to Stassney	Stassney to Rt. 71	Rt. 71 to MLK Blvd.	MLK Blvd. to Rt. 183	Rt. 183 to Yager Ln.
Outputs					
Mobility					
Avg. Daily Volume	118,970	145,240	201,900	205,650	159,180
Daily Capacity	112,500	112,500	112,500	112,500	112,500
V/C Ratio	1.06	1.29	1.79	1.83	1.41
Link Length (miles)	0.7	1.4	4.6	4.6	4.6
Min Peak Spd (mph) AM	8 (NB)	19 (NB)	12 (NB)	13 (SB)	23 (SB)
Min Peak Spd (mph) PM	56 (SB)	50 (SB)	9 (SB)	27 (NB)	23 (NB)
Speed (mph): 24 hr Avg.	54.4	54.4	54.4	54.4	54.4
Travel Time (min): 24 hr	0.77	1.54	5.07	5.07	5.07
Facility Usage					
VMT per day	83,279	203,336	928,740	945,990	732,228
Output (Veh/hr): 24 hr	4,957	6,052	8,413	8,569	6,633

Sources: Austin Transportation Study (ATS) 1993 volume and capacity data.
City of Austin 1995 congestion management travel time data.
Texas Natural Resources Conservation Commission (TNRCC) 1993 congestion management and speed data.

Table 4.2 Houston Highways - IH-10

West *East*	West of Gessner	Gessner to IH 610	IH 610 to IH 45	IH 45 to Rt. 59	Rt. 59 to IH 610	IH 610 to Rt. 8	Rt. 8 to Rt. 330
Outputs							
Mobility							
Avg. Daily Volume	147,000	217,000	180,000	102,000	117,000	145,000	77,000
Daily Capacity	112,500	112,500	112,500	112,500	112,500	112,500	112,500
V/C Ratio	1.31	1.93	1.60	0.91	1.04	1.29	0.68
Link Length (miles)	2.1	5.4	5.5	2.1	5.1	7.1	7.5
Speed (mph): 24 hr Avg.	54.3	54.3	54.3	54.3	54.3	54.3	54.3
Peak Avg.	46.3	46.3	46.3	46.3	46.3	46.3	46.3
Travel Time (min): 24 hr	2.3	6.0	6.1	2.3	5.6	7.8	8.3
Facility Usage							
VMT per day	308,700	1,171,800	990,000	214,200	596,700	1,029,500	577,500
Output (Veh/hr): 24 hr	6,125	9,042	7,500	4,250	4,875	6,042	3,208

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1993 congestion management and speed data.

Table 4.3 Austin - Dallas-Fort Worth Intercity Highway - IH 35

South *North*	Loop 1 to Rt. 79	Rt. 79 to Rt. 29	Rt. 29 to Rt. 190	Rt. 190 to Rt. 36	Rt. 36 to Waco	Waco to Rt. 22	Rt. 22 to I35 Split
Outputs							
Mobility							
Avg. Daily Volume	118,000	69,000	33,000	60,000	39,000	41,000	38,000
Daily Capacity	112,500	112,500	112,500	112,500	112,500	112,500	112,500
V/C Ratio	1.05	0.61	0.29	0.53	0.35	0.36	0.34
Link Length (miles)	6	8	34	8	33	34	3
Facility Usage							
VMT per day	708,000	552,000	1,122,000	480,000	1,287,000	1,394,000	708,000
Output (Veh/hr):24 hr	4,917	2,875	1,375	2,500	1,625	1,708	4,917

Source: Texas Department of Transportation (TxDOT) 1994 traffic volume data

Table 4.4 Austin - Houston Intercity Highway - Rt. 290

West *East*	Rt. 183 to Rt. 95	Rt. 95 to Rt. 21	Rt. 21 to Rt. 77	Rt. 77 to Rt. 36	Rt. 36 to Hempstd	Hempstd Rt. 1960	Rt. 1960 to Rt. 8
Outputs							
Mobility							
Avg. Daily Volume	17,300	7,900	10,400	5,800	8,900	23,000	81,000
Daily Capacity	29,000	29,000	29,000	29,000	29,000	29,000	29,000
V/C Ratio	0.60	0.27	0.36	0.20	0.31	0.79	2.79
Link Length (miles)	19	16	13	35	22	32	12
Facility Usage							
VMT per day	328,700	126,400	135,200	203,000	195,800	736,000	972,000
Output (Veh/hr): 24 hr	721	329	433	242	371	958	3,375

Source: Texas Department of Transportation (TxDOT) 1994 traffic volume data

At the highway link level, daily traffic volume information was readily available from the locality or state. Peak hour volume, a desirable measure, especially in urbanized areas, could not be obtained, although it is most likely collected for major links. Capacity can be determined based upon highway characteristics. However, since peak hour volume is unavailable, volume-to-capacity ratio can only be determined for daily volume. Vehicle miles traveled (VMT) was derived from link length and link volume.

A measure of passenger miles traveled (PMT) could be determined given a value for passengers per vehicle, but in the absence of a reliable regional value, it was decided not to substitute some rough national average. This was the case with other measures, such as energy consumption and emissions: highly aggregated, per-VMT values can be obtained, but the use of such values would reduce accuracy and to some degree defeat the purpose of the performance measurement.

In fact, this problem occurred for measures in most other modes as well. In such a situation it would be preferable to obtain more disaggregate data for these measures. Even if this data cannot be found for the link level, as will generally be the case, it will often be available on a more aggregate level, such as an urbanized area or a county. If necessary, link level data can be derived from this moderately aggregated data, with more accuracy than from much more highly aggregated data, at the state or even national level.

Table 4.5 Austin Roadways - Aggregate Measures

Outputs	
Mobility	
System Usage	
VMT per day	17,540,567
Delay: Total Vehicle Hours per day	50,000
Delay per VMT (min)	0.17
Cost-Effectiveness	
Capital Cost per year	$ 48,759,978.00
Net Cost per 1000 VMT	$ 7.62
Outcomes	
Environmental	
Energy Efficiency	
Energy Consumed	
Gallons of Gasoline	30,000,000
Btus	3,750,000,000,000
Energy Intensity (Btus per VMT)	213,790
Air Quality	
Total Emissions	
NO x (tons per day)	52
VOC (tons per day)	44
CO (tons per day)	344
Emissions Rate	
NO x (lbs per 1000 VMT)	5.92
VOC (lbs per 1000 VMT)	4.97
CO (lbs per 1000 VMT)	39.18
Social	
Safety	
Accidents / Incidents per year	14,875
Fatalities per year	49
Injuries per year	12,386
Accidents per Million VMT	2.32
Fatalities per Million VMT	0.00765
Injuries per Million VMT	1.93
Economic	
Employment Impact (Jobs per year)	386

Sources: TNRCC 1993 congestion and air quality management data.
TxDOT 1994-1995 project cost data.
City of Austin 1992 roadway energy consumption estimates.
Texas Department of Public Safety (DPS) 1994 motor vehicle accident data.
BTS: 1992 urbanized areas delay data.
FHWA: 1991 Highway Statistics

Table 4.6 Houston Roadways - Aggregate Measures

Outputs	
Mobility	
System Usage	
VMT per day	103,916,926
Vehicle Hours per day	2,719,695
24 hr Avg. Vehicle Speed (mph)	38.21
Peak Avg. Vehicle Speed (mph)	34.88
Delay: Total Vehicle Hours per day	416,000
Delay per VMT (min)	0.24
Cost-Effectiveness	
Capital Cost per year	$ 497,235,678.00
Net Facility Cost per 1000 VMT	$ 13.11
Outcomes	
Environmental	
Air Quality	
Total Emissions	
NO x (tons per day)	405.4
VOC (tons per day)	208.7
CO (tons per day)	2,166.0
Emissions Rate	
NO x (lbs per 1000 VMT)	7.80
VOC (lbs per 1000 VMT)	4.02
CO (lbs per 1000 VMT)	41.69
Social	
Safety	
Accidents / Incidents per year	56,140
Fatalities per year	179
Injuries per year	55,219
Accidents per Million VMT	1.48
Fatalities per Million VMT	0.00472
Injuries per Million VMT	1.46
Economic	
Employment Impact (Jobs per year)	3,935

Sources: TNRCC 1993 congestion and air quality management data.
TxDOT 1994-1995 project cost data.
Texas Department of Public Safety (DPS) 1994 motor vehicle accident data.
BTS: 1992 urbanized areas delay data.
FHWA: 1991 Highway Statistics

Data for measures of cost-effectiveness and environmental, social, and economic outcomes could not be obtained for the link level. However, data for many of these measures was obtained for the urbanized area's overall roadway network. Congestion management information on total VMT serves as the basic denominator for expressing measures as per-VMT rates (again, per-PMT rates would be preferable, and could be easily determined given an accurate value for passengers per vehicle). Expressing these measures in terms of PMT enables some degree of intermodal comparison.

The average daily traffic volumes are adjusted to account for truck traffic, and the aggregate roadway data includes motor freight traffic. However, more detailed data on motor freight performance could not be obtained, although such data is collected through the Commodity Flow Survey (CFS). The 1993 CFS data is currently being finalized, and will not be available for several months. This deficiency impacted other modes as well.

Air Data

Table 4.7 Houston Airports

	Houston Intercontinental (IAH)	William P. Hobby Airport (HOU)	Ellington Field (EFD)
Outputs			
Mobility			
Volume (per year)			
Enplaned Passengers	9,696,901	4,061,425	-
Enplaned Tons - Freight	79,332.66	4,840.79	4,840.79
Enplaned Tons - Mail	22,392.70	1,208.72	-

Source: 1993 Airport Activity Statistics of Certificated Route Air Carriers.

Table 4.8 San Antonio Airports

	San Antonio International Airport (SAT)	Kelly Air Force Base (SKF)
Outputs		
Mobility		
Volume (per year)		
Enplaned Passengers	2,753,008	4,266
Enplaned Tons - Freight	15,556.66	2,882.38
Enplaned Tons - Mail	9,720.02	-

Source: 1993 Airport Activity Statistics of Certificated Route Air Carriers.

Disaggregate data for air mode measures was very difficult to obtain, beyond data for passenger and freight enplanements. Data for intercity airway links could not be obtained, although passenger link information is collected by the Federal Aviation Administration's (FAA's) Office of Airline Information (OAI) in the form of a 10% sample of all passenger tickets on certificated route air carriers. Data for air mode outcomes could only be obtained at a nationally aggregated level. Data for air freight performance measures can be obtained from the CFS.

Rail Data

Table 4.9 Rail Freight - Originating Austin

Outputs	
Mobility	
Volume (Tons per year)	226,437
Capacity (Tons per year)	16,424
V/C Ratio	13.79
Facility/System Usage	
Ton-Miles	34,672,111
Cost-Effectiveness	
Revenues per year	$ 1,826,663.00
Revenue per 1000 Ton-Miles	$ 52.68

Source: 1992 Rail Freight Waybill Sample data.

Table 4.10 Rail Freight - Terminating Houston

Outputs	
Mobility	
Volume (Tons per year)	37,883
Capacity (Tons per year)	36,733
V/C Ratio	1.03
Facility/System Usage	
Ton-Miles	47,957,356
Cost-Effectiveness	
Revenues per year	$ 1,504,553.00
Revenue per 1000 Ton-Miles	$ 31.37

Source: 1992 Rail Freight Waybill Sample data.

Data obtained from the 1992 Rail Freight Waybill Sample was relatively limited and incomplete. The tremendous number of records prevented analysis of a full year's data, so the measures above represent only a partial year's data. In addition, many of the records did not include origin and destination data. Furthermore, data on freight car capacity was likely inaccurate: while the volume-to-capacity ratio for the freight shipments terminating in Houston is reasonable, that for shipments originating in Austin is not. Outcome data could only be obtained for the national level. More accurate and complete data should be available from the CFS. Amtrak was unwilling to provide data on intercity passenger rail performance.

Water Carrier Data

Table 4.11 Port of Houston

Outputs	
Mobility	
Volume (Tons per year)	141,476,979
Domestic	64,329,185
Foreign	77,147,794
Imports	51,446,146
Exports	25,701,648
Facility Output (tons / hr)	16,150
Outcomes	
Environmental	
Air Quality	
Total Emissions	
NO x (tons/day)	13.23
VOC (tons/day)	1.21
CO (tons/day)	1.07
Emissions Rates	
NO x (tons/million tons cargo)	34.14
VOC (tons/million tons cargo)	3.12
CO (tons/million tons cargo)	2.77
Natural Resource Impact	
Pollution Incidents per year	210
Incidents per Million Tons	1.48
Social	
Safety	
Accidents / Incidents per year	
Allisions, collisions	53
Fires, explosions	3
Casualties	19
Deaths	-
Rates, per Million Tons	
Allisions, collisions	0.375
Fires, explosions	0.021
Casualties	0.134
Deaths	-

Sources: U.S. Army Corps of Engineers Waterborne Commerce Statistics Center (WCSC) 1993 port tonnage data.
U.S. Coast Guard 1993 pollution and safety data.
TNRCC 1994 emissions data.

Port data was fairly accessible due to monitoring by the U.S. Army Corps of Engineers and the U.S. Coast Guard. Data for environmental outcomes was especially detailed. However, data for waterway links, with origin and destination ports, as well as total trip information, was lacking in these databases. Better data for links and overall freight trips should be available from the CFS.

Transit Data

Table 4.12 Austin - Capital Metro Transit System

	Motor Bus	Demand Resp.	Van Pool	Total
Outputs				
Mobility				
Volume (pax trips)	25,503,400	419,700	261,300	26,184,400
Capacity (peak hr veh)	244	68	2	314
Average Speed (mph)	15.54	18.55	40.10	16.63
System Usage				
Revenue Vehicle Hrs	617,400	162,500	15,300	795,200
Revenue VMT	9,594,600	3,014,600	613,500	13,222,700
PMT	82,485,300	3,591,500	4,266,800	90,343,600
System Output				
Trips / System Hr	3,882	63.9	39.77	3,985
Trips / Rev Veh Hr	41.31	2.58	17.08	32.93
Cost-Effectiveness				
Capital Cost	$ 9,643,300.00	$ 1,597,400.00		$11,240,700.00
Operating Cost	$35,705,800.00	$11,747,600.00	$564,700.00	$48,018,100.00
Total Cost	$45,349,100.00	$13,345,000.00	$564,700.00	$59,258,800.00
Revenues				
Passenger Fares				$ 494,228.40
Total Direct Op Revs				$ 536,895.60
Outcomes				
Environmental				
Energy Efficiency				
Diesel Fuel (gal)	2,123,000	81,700		2,204,700
CNG (lbs)	54,800	747,800		802,600
Gasoline (gal)		252,100		252,100
Total Energy (Btus)	295,586,294,800	58,212,327,800		353,798,622,600
Intensity (Btus/PMT)	3,584	16,208		3,916
Social				
Safety				
Accidents/Incidents	50	18		68
Fatalities	0	0		0
Injuries	41	14		55
Rates per million PMT				
Accidents/Incidents	0.606	5.012		0.753
Fatalities	0.000	0.000		0.000
Injuries	0.497	3.898		0.609

Source: Federal Transit Administration (FTA) Section 15 data.

Transit data is quite complete and comprehensive due to FTA requirements for Section 15 data reporting. If additional data, such as employment and economic information, is needed, or if more detailed information line or station data is needed, this data should be obtained from the transit agency in question.

Additional transportation data for the central Texas region is included in the Appendix.

SUMMARY

The extensive data needs of the NTS will require the use of data from many existing databases. Most of these databases are maintained by governmental agencies, including transportation, environmental, energy, and public safety agencies, from the federal level down to the local level. Supplemental data for the NTS may need to be obtained from the private sector, especially for freight transportation, or else from special NTS data collection efforts, such as surveys. Due to the expense and difficulty of collecting new data and obtaining private sector data, the NTS should rely upon existing governmental sources as much as possible.

Numerous potential sources of data have been identified. Collectively, these data sources capture most of the data sought for the NTS. However, as the data sample showed, much of this data is difficult to obtain, especially for a desirable level of aggregation. In some cases, this data does exist, and can be obtained. In other cases, the data does not exist at the desired level of aggregation. This data may be assigned to NTS facilities through modeling, as long as it is not so highly aggregated that it is inappropriate for assignment to a more detailed level. If so, more disaggregate data should be obtained, or the data should be left in an aggregated form.

For all the NTS performance measures, the best sources of data must be identified from among those proposed, and protocols must be established for procuring and adapting the data to the measures. The use of GIS databases, both for the NTS and for the data sources that support it, will facilitate this, as the subsequent chapter on GIS will discuss.

CHAPTER 5. POLICY-MAKING FRAMEWORK

INTRODUCTION

This report has proposed performance measures and objectives for the NTS. At this point it is necessary to specify the process by which DOT can use the performance measures to pursue the objectives of the NTS. Since these objectives are in the area of guiding national transportation policy, this process is best described as a policy-making framework. The following general framework is based largely on the four objectives tentatively identified by DOT for the NTS in March 1995. The objectives are accompanied by questions that must be answered in order to make decisions.

NEED FOR A POLICY-MAKING FRAMEWORK

The vast majority of transportation project programming and investment decisions will be made at the state and MPO levels. This is where the authority for these decisions lies, and the level that is most appropriate to project-level decisions. However, DOT must still safeguard federal investment and ensure that the transportation system effectively serves national needs and priorities. DOT must therefore use the NTS to monitor the nation's transportation network and guide transportation policy.

Under ISTEA, the emphasis in transportation planning is upon intermodal and multimodal alternatives. This is true for project programming at the state and MPO level, and should be true for policy-making at the federal level. It is for this reason that the intermodal nature of the performance measures has been stressed, and this is also why the goals of the NTS have been expressed in a non-mode-specific manner.

Of course, each mode has advantages and disadvantages. Air travel is faster but more expensive than highway modes. Rail is more energy efficient but offers less accessibility than highway. The various criteria of the proposed performance measures attempt to capture these relative advantages and disadvantages between modes. Part of intermodal transportation planning, from a project programming level up through a policy-making level, is making strategic trade-offs between modes and between goal criteria.

This report proposes a very general framework for national policy-making based upon threshold analysis and multi-criteria decision-making. The first part of this section describes some multi-criteria decision-making models that are in use or have been proposed for intermodal project and investment decision-making at the state or MPO level. Since these models are constrained geographically and limited in their objectives to selecting transportation projects for implementation, they can be specified in a more detailed and concrete manner than the NTS, whose policy-based objectives require more flexibility. However, these models are nonetheless instructive about the way that multi-criteria analysis can be used in policy and planning situations.

PROPOSED POLICY-MAKING FRAMEWORK

The NTS policy-making framework proposed here is a general outline for using the proposed performance measures to achieve the goals of the NTS. It is based upon the objectives of the NTS, which are accompanied by questions that will help shape the policy-making process.

The framework will rely heavily upon threshold analysis and multi-criteria analysis. Unlike the models described above, this framework is designed to support national transportation policy-making, not discrete project programming. Because it must be applied flexibly for different policies and situations, no thresholds or weighting functions can be specified or prescribed in advance, since these will be different depending upon the circumstances. A critical feature of the NTS is that its performance monitoring capabilities can define the circumstances that inform the policy-making decisions. That is, performance in a given mode and/or goal criterion can shape policy imperatives for other modes and/or criteria; this is facilitated by the interaction possible between the different modes and elements of the NTS.

System Monitoring, Identification of Weaknesses

- How well is the transportation system performing relative to national goals?
- Are there certain threshold levels of performance that a facility or system should meet to serve national goals?
- How can performance thresholds with respect to national goals be specified for the NTS?
- Does the facility or system in question meet the acceptable performance thresholds?
- Is there a weakness or deficiency with a given facility or system?

The most basic function of the NTS is to monitor the performance of the nation's transportation network. The NTS is uniquely able to monitor and assess this performance because of its comprehensiveness, in terms of the transportation system's different modes and many goals. The NTS performance measures reflect this comprehensiveness, and facilitate the creation of a unified system summary, such as the "State of the Transportation System Report" cited by DOT as a projected product of the NTS.

The system monitoring features of the NTS will also allow it to identifying weaknesses in the network, such as poor connection points, facilities with reduced capacity relative to adjacent facilities, congested facilities, areas with unacceptable emissions levels, facilities with high accident rates, or areas with poor accessibility. In order to recognize these weaknesses, the NTS must specify certain threshold levels of performance that the major elements of transportation system should meet.

The NTS performance measures will naturally serve as the indicators to which these thresholds will be compared. This will not be an occasion for the exertion of increased federal control over states or MPOs. Since the NTS is a tool for national transportation planning and policy, its priorities will sometimes diverge from those of states and MPOs. This divergence will often be apparent from the threshold levels, which may not reflect state, regional, or local needs. If threshold levels are not met, this information is used to shape national policy, not justify federal intervention.

The levels of these thresholds will be determined by various means. Some may be determined by functional requirements: volumes in a given mode served by an intermodal connector necessitate comparable capacities for other modes served by that connector and for the connector itself. For example, a port capable of high ship volume may be limited in its operations by highway or railway access with inadequate capacity, or a transit system's ridership may suffer due to inadequate feeder services or undersized park and ride facilities.

Some thresholds may be based on such unique federal priorities as national defense needs; these are especially important for Strategic Highway Network (STRAHNET) routes. For environmental measures, acceptable values will often be determined by federal environmental regulations which are already in force, such as 1990 Clean Air Act Amendments (CAAA). For non-attainment areas under the CAAA, these thresholds will be especially important, for they will influence other aspects of the transportation system.

Some thresholds may be set nationally, while others can be given levels set nationally as a function of population, geographic area, or other specialized conditions. In some situations, the overall monitoring performed by the NTS will be used to determine certain thresholds. The performance of facilities or systems may be used to determine thresholds for other facilities, sometimes in other modes. The emissions thresholds cited above are a good example of this; in non-attainment areas under CAAA, transportation funding uses are constrained to prevent additional SOV capacity, and trip reduction programs necessitate increased usage of alternate modes.

Threshold levels based upon the interaction between different modes and goal criteria may also be predicated upon policy goals. For example, if transit ridership or accessibility in an urbanized area is low, corresponding to poor transit service, a higher threshold for roadway performance may be set than if transit service is good, thus ensuring that travelers will have a viable travel option. This can work in the opposite direction as well: if other concerns, such as emissions or neighborhood impact, prevent improvement of roadway service, the policy requirements may instead demand a higher standard for transit service in response to poor roadway service. Or if roadway access to a major airport suffers from heavy congestion, higher rail accessibility thresholds may be required. Again, the results of these threshold analyses will be used not for direct intervention, but for policy-making purposes. The aim of this objective is to detect the weaknesses and deficiencies in the network; the way in which these problems can be addressed is discussed in the following section.

In some cases, states, MPOs, and/or the private sector may be solicited for input into setting thresholds. Such input might be solicited if more detailed information on a facility or system were required, or if the threshold were based on a performance partnership, a voluntary agreement between DOT and states or MPOs in which performance targets are set cooperatively and progress toward these targets is measured.

Threshold values for freight facilities, or for facilities essential to freight movement, may be based on outreach to shippers and carriers, or on national priorities related to freight. Special areas of interest with respect to freight needs include infrastructure condition, international trade, connectivity, and sources of bottlenecks in the freight network. It is in the interest of both the freight sector and DOT to address any problems in these areas. Even if this data were qualitative or anecdotal, it could aid in monitoring and determining whether or not a problem exists. Due to the potential difficulties in dealing with the freight sector, it should be as targeted as possible.

If it is determined through the threshold analysis that a problem or deficiency may exist, a more extensive analysis should be conducted in order to determine the specific nature and scope of the problem. Although the NTS is not designed to be another layer of federal monitoring to direct state and MPO transportation policy, there may be some cases in which the NTS detects a problem that concerns a state, MPO or private entity, and requires assistance with a solution. In such situations, the benefits to the state, local or private partner should be clear and compelling. For the most part, however, the NTS should address problems related to national priorities, and which impact national policy and planning.

Address National Goals and Problems

- What is the nature of the problem?
    - With what facility, system, mode, region, and goal does this problem exist?
    - Does this problem exist with other facilities or systems? If so, how are these problems related? Is there a pattern that should be addressed?
- What are the policy alternatives or solutions to be considered?

- What are the relative merits of the different alternatives? What are the trade-offs between different alternatives and different modes, in terms of both outputs and outcomes?

If a problem is detected and it relates to a national policy concern, then DOT must take action. The problem could also be of a limited scope, perhaps with a facility that has direct bearing on a national transportation interest, such as a national defense route or a key international trade border crossing. More likely, however, the problem will be systemic, on a national or regional scale, that does not fall within the purview of any state or MPO. An evaluation of the problem and the generation of a set of solution alternatives is required.

The detection of national problems will be an outgrowth of the NTS system monitoring and its threshold analyses. This monitoring and analysis may reveal similar weaknesses in many regions throughout the nation. For example, many high volume ports may experience an unacceptable number of pollution incidents, or intercity rail safety may be at unacceptable levels in some regions. The national scope of the NTS will enable it to detect such patterns.

A set of feasible policy alternatives for solving the problem must be generated. The alternatives must be based on system conditions, system requirements, and opportunities for improvements and solutions. The alternatives should offer a variety of modal and intermodal policy options, and a range of trade-offs between the selection criteria. Since these are proposed alternatives, data for the measures of each alternative's performance must be projected. This can be done based on demand forecasting, data for comparable transportation systems, and projected environmental, social, and economic impact.

The fairly general nature of the NTS performance measures will simplify these forecasts, though they should still be adequately detailed for making national policy decisions. The unified structure of the NTS will also facilitate projections of the impacts of different policy alternatives on different modes, and on the system in general.

In order to evaluate the policy alternatives, a multi-criteria analysis of the alternatives' projected performance must be undertaken. However, a simple weighting function such as the one used by MTC cannot be prescribed, since this would be far too rigid for the varied needs of the NTS. The relative importance of the different measures and modes will depend upon the policy goals and the circumstances of the facilities and systems affected.

For example, a policy designed to address highway safety will naturally place the most weight on highway safety, while monitoring the impact of the policy alternatives upon the other measures, including cost, mobility, and emissions, as well as the impacts upon other modes. The policy decision will be based upon the degree to which highway safety is improved, and the acceptability of the trade-offs with other goals and other modes. This multi-criteria analysis function and its trade-offs will differ from the analysis and trade-offs relating to motor freight capacity improvements desired at international border crossings. The evaluation of the impacts of policy decisions on national problems must be sufficiently flexible to recognize varying priorities.

Progress Toward Performance Targets

- Is a given goal area suitable for a performance partnership between DOT and a state or MPO?
- What are appropriate target thresholds for a performance partnership?
- Does the state or MPO meet target performance thresholds?
- What does the state or MPO receive in return for meeting a performance target? Regulatory relief? Simplified federal rules?

DOT had previously considered allowing waivers of set-asides of Unified Allocation (UA) transportation funds for recipients that meet certain qualifications or transportation performance standards. In relation to this plan, this report had previously recommended using the NTS performance measures as a basis for granting these waivers. It now appears that DOT will not pursue this plan. This report has therefore abandoned its recommendations relating to the waivers.

Another possible national transportation policy, however, is the concept of "performance partnerships." These could be voluntary and mutual agreements between DOT and states and/or MPOs that identify targets and strategies for improving the nation's transportation network in a manner that serves both national and state and/or local needs. The NTS performance measures can be used as a basis for setting these performance targets and for measuring progress toward them. Again, these measures are to be used not for comparison of states and MPOs to one another, but to describe transportation performance and how it changes over time.

The setting of the performance targets would be a cooperative process between DOT and the state or MPO. These targets could be based upon certain threshold levels set as a function of monitoring the system and detecting weaknesses. However, these thresholds are used originally for policy purposes; their applicability to performance targets would not be automatic. Even if these thresholds were used as performance targets, this would have to be agreed upon by DOT and the state or MPO.

These performance partnerships should function as a contract between DOT and the state or MPO, implying some *quid pro quo* for the state or MPO in exchange for meeting the target. Existing federal regulations relating to state and MPO transportation planning are rigorous enough, and states and MPOs cannot be expected to voluntarily accept further standards or monitoring without the possibility of sufficient reward. Such incentives must be developed carefully in order to ensure equity and fairness between recipients and to safeguard existing federal rules. However, possibilities for such incentives include some relaxing of federal regulation or simplification or streamlining of federal rules in the areas in which states or MPOs demonstrate superior performance by meeting targets.

Support of State and MPO Planning

- Does the performance information supplied by states and MPOs satisfy all monitoring needs?
- Has the decision-maker identified the relevant issues, trade-offs, and alternatives?
- Can the NTS assist in state and local transportation decision-making? Are the NTS performance measures and performance-based planning models of value to state and MPO planners?
- What are the appropriate decision-making models that DOT or other states or MPOs have used that might be applicable in this situation?

ISTEA has already encouraged a much greater emphasis on performance-based planning at the state and MPO level, largely through its requirement for the six transportation management systems. Through these systems, ISTEA has required that the performance of the state's transportation system be quantitatively measured for a variety of modes and criteria. States must make use of these systems to make transportation planning more performance-based than it has been in the past.

At the same time, states and metropolitan areas are being pressed by extensive and sometimes redundant federal regulatory requirements for transportation planning and implementation. For example, environmental regulations alone can be complex and redundant. MPOs, states and the federal government recognize this. The NTS can help consolidate and streamline the regulatory process by serving as a mechanism for federal regulation. This process could rely on the criteria that are already captured by the NTS analysis, such as emissions, energy efficiency, and natural resource impacts, to name a few.

The NTS can also facilitate better performance-based planning by serving as a clearinghouse for data, performance measures, and effective planning strategies. All of these can serve as guides and assist states and MPOs in their own planning and policy-making. The NTS and the ISTEA-mandated state management systems can therefore facilitate greater uniformity of data, performance measures, and decision-making models.

APPLICATION OF POLICY-MAKING FRAMEWORK

This framework is designed to be flexible and allow adaptation to a variety of policy goals, regions, and levels of analysis. It must also be flexible in terms of the types of transportation alternatives that it considers. Special attention must be paid to the way in which it can adapt to high technology aspects of transportation, such as intelligent transportation systems (ITS), and technologies that can redefine transportation, such as telecommunications and telecommuting. Transportation control measures (TCMs) must also be considered as viable alternatives that can offer cost effective mobility enhancement. The performance measures and framework must be sensitive to these issues and the impacts that they can have on the transportation system.

SUMMARY

This chapter has described a general framework for policy-making under the NTS. This framework uses the NTS performance measures as the tool for achieving the proposed objectives of the NTS: monitoring the national transportation network and identifying weaknesses through the use of threshold analyses; addressing national problems and selecting policy alternatives through the use of multi-criteria analyses; setting and achieving performance targets through cooperative agreements between DOT and states and/or MPOs; and supporting state and MPO transportation planning by sharing data, performance measures, and planning models. This policy-making framework is the basis for many of the GIS-based tools that are described in the following chapter on a GIS platform for the NTS.

CHAPTER 6. GEOGRAPHIC INFORMATION SYSTEM (GIS) PERFORMANCE EVALUATION PLATFORM FOR THE NTS

INTRODUCTION

This report has discussed the nature of the NTS, the measures by which its performance is to be evaluated, the data that can be used to support these measures, and the policy-making framework for using the performance measures to achieve the objectives of the NTS. This chapter will address the applicability of geographic information systems (GIS) to these components of the NTS. This section will discuss the characteristics and features of GIS that make it appropriate to use with the NTS; other GIS uses that demonstrate its applicability to the NTS; the components of an NTS GIS; the GIS-based analytical tools that the NTS will require; how these tools can be used to help achieve the objective of the NTS; and some other technologies, most prominently Intelligent Transportation Systems (ITS) technologies, that can be expected to work in concert with GIS in order to make the NTS an effective policy tool.

GEOGRAPHIC INFORMATION SYSTEMS (GIS)

The NTS, like many other transportation management systems, has complex and demanding needs. The NTS is based on the national transportation system itself, the physical transportation infrastructure. The physical network characteristics of this infrastructure are critical to any modeling or analysis of the NTS, so any NTS evaluation system must be able to recognize and represent this physical network.

As has already been made clear, the NTS will rely upon a great deal of data, from many different sources. It must be able to not only store this data, but analyze it in order to generate the desired NTS performance measures, facilitate planning and policy-making relative to the objectives of the NTS, and to reveal patterns in transportation operations that can aid in planning and suggest new policy objectives for the NTS.

An excellent platform for such an NTS performance evaluation system is a Geographic Information System (GIS). A GIS is a map-based computer system designed to capture, manage, manipulate, analyze, and display data. A GIS attaches data and performance measures to a mapping of physical, spatial components, and is equipped with tools for analyzing these data and performance measures.

FEATURES OF A GIS FOR THE NTS

The point has already been made that an effective NTS must be more than an inventory and mapping of nationally-significant transportation facilities and systems, although this is one facet of the NTS. The NTS must also include the data describing the transportation network and the analytical system that enables transportation planning and policy-making. It is not just that GIS is ideally suited to meeting these needs is an understatement; in fact, GIS, in combination with ITS and other developing technologies, make possible such an NTS as the one proposed here.

The basic data for a GIS consists of geographic data and attribute data. The geographic data describes the location of the feature in question, in terms of x, y coordinates, and allows the conversion of data into a map. The geographic data can describe the feature in two basic ways. The first is a grid, or raster, format. This format divides the map into a grid, and assigns features to a given grid location. This method of geographic assignment is more suited to area-oriented analyses, and accuracy will be dependent upon grid resolution. The second method of mapping geographic data is by vector format. This is a link and node based format, that defines map features in terms of x, y coordinate specified node points, and the two-dimensional links connecting them. Areas can be defined by polygons formed by closed loops of links and nodes. This vector method requires more computing time, but is more suited to the needs of a network-based transportation network, with its two-dimensional corridors such as highways and railroads (Zhang 1993, 18).

In the case of the NTS, the links will correspond to the two-dimensional transportation corridors, such as highways, railroads, and waterways. The nodes will correspond to connections between links; some of these will be intermodal connectors, but most of them will be in a single mode. The intermodal connectors, such as ports and airports, will have important data attached to them, but so will the single mode connectors, such as highway interchanges and railroad switching yards.

The attribute data is the data which describes the geographic features, in this case the transportation facilities and systems. For the NTS GIS, this attribute data will be descriptive data about the transportation facilities and systems, the performance measures proposed, and the data that support these measures. This attribute data can be related to the geographic data in different ways. The most basic method is to tie the attribute data directly to the geographic data, in a one-to-one manner, essentially in the same data table. In the case of the NTS, this would mean creating one data for each link or node. This data table would contain the geographic information as well as all the attribute data. This table would have one performance measure or data point for each link.

Although this is a straightforward approach, it is a very inflexible one. It cannot easily handle changes in attributes over time or for different conditions. It would also force many attributes to fit to a single link or node when these measures would be more applicable to a scale that is either smaller or larger than a single link or node. It would not allow more than one set of performance measure for a given link, nor would it allow a single set of performance measures to span more than one link.

An alternative approach is dynamic segmentation. This feature relies upon linked relational data tables. In such an arrangement, geographic data is contained in one data table, and marked with some unique code identifying the link or node to which it corresponds. This unique code can be used to link it to one or many other data tables, containing attribute data for that link or node.

A GIS that is based on such linked tables is much more flexible than one based on a single table. It allows for separate tables for different sets of performance measures within a single link or node, or else it allows for a single table for one set of performance measures that spans more than one link, in cases when such approaches are necessary or convenient. The performance measures describing a given link might change considerably over the course of the link, or might remain the same into a portion of another link. It allows this to be accomplished without cluttering the network with new nodes for every point at which link attributes might change.

The NTS is a complex network, and one that would benefit from the use of a dynamic segmentation approach. In addition, the NTS should take advantage of the flexibility that the use of linked relational data tables offer in general. Different data tables can be used for different modes, different measures, different segments of the network links, and different time frames, as long as they are referenced to the appropriate links and nodes. This is especially useful when multiple modes use the same facilities. For instance, one data table can be used to describe the attributes of highway link A-B with respect to peak hour congestion and travel time, while another data table can be used to describe the attributes of highway link A-B-C with respect to 24-hour motor freight volume.

Cross-referenced data tables would be useful in the case of a link that is heterogeneous with respect to one or a few performance measures, such as speed, but homogeneous with respect to others, such as volumes, emissions, and energy use. It also allows for separate tables with different attributes for different times of day and different study years. Such flexibility is essential with a network like the NTS, which is multimodal, intermodal, and based on such diverse data sources.

Critical to the implementation of such an extensive GIS as the NTS is the prevalence of GIS in transportation and related fields and the ease of converting and combining GIS databases. Transportation planners at all levels recognize the utility of a GIS format for transportation databases and analysis systems, and they are striving to put more and more data and analysis tools into GIS format. Numerous examples of such ongoing conversion to GIS were discovered through research for this report. At the federal level, there are plans to add Highway Performance Monitoring System (HPMS) data to the spatial National Highway Planning Network (NHPN) GIS. The Texas Department of Transportation (TxDOT) plans to represent highway expenditure data spatially, on a GIS of the network segments on which the money was spent. As a result, more and more data, including much or most of the data identified in the previous section on NTS data sources, is in GIS format or will be in the foreseeable future.

However, this usefulness of this data would be severely diminished if it were not "portable" between different systems. Fortunately, virtually all major GIS programs are equipped with utilities for converting data from other programs. This means that GIS data from different systems at different levels of jurisdiction can be combined into the same GIS. Data will still need to be cleaned and adapted to address differences in level of detail, form, and measures of performance. However, the ability of GIS programs to convert data from one to another will facilitate the process of constructing a national GIS database for the NTS.

OTHER GIS TRANSPORTATION PLANNING APPLICATIONS

Although the GIS technology was developed for land use and environmental purposes, its transportation applications are apparent. The geospatial nature of the transportation network itself, combined with the high level of transportation-related data collection and analysis, make transportation a natural field for GIS use.

Many transportation databases and databases with relevance to transportation applications have been put in GIS format. There are examples of these at the federal level. Two which have been referred to in this report are the National Transportation Atlas Databases, which contain the geographic data for mapping most of the nation's transportation infrastructure, and the various GIS databases of the Bureau of the Census, which contain important land use and commuting data that are essential to transportation planning. Other GIS databases exist or are in planning at the federal, state, and local levels; at the state and local levels, these databases are often connected to the transportation management systems mandated by ISTEA. Many of these databases move beyond geographic mapping of transportation facilities to more fully utilize the analytical capabilities of GIS.

A primary example of transportation GIS is the National Transportation Network Analysis Capability (NTNAC), a system which relates directly to this research effort. The NTNAC is the plan by the Oak Ridge National Laboratory (ORNL) for a national, multimodal GIS for supporting the NTS. The NTNAC recognizes the need for a geospatial network-based system for quantitative transportation, with similar indicators of performance as those recommended in this report (Southworth 1995, 4).

The NTNAC will comprise several "layers" of geospatially referenced data. The first is the facilities layer, based upon the National Transportation Atlas Databases, which will map the physical infrastructure. This network layer will be supported by the other layers: a services layer, which contains data on the transportation services that the network provides; a flows layer, containing information on volumes; and a background layer, containing other data, such as environmental and climatic data relevant to the transportation system (Southworth 1995, 8). The mission of the NTNAC is clearly similar to that of the NTS proposed in this report; the plan for the NTNAC can therefore be used to inform the GIS structure for this report's NTS.

Researchers at Louisiana State University have implemented a GIS-based system for use with Baton Rouge, LA's Congestion Management System. Measures of performance in terms of travel times and travel speeds are determined using a GIS in combination with floating car experiments aided by the use of a Global Positioning System (GPS). The Interstate Highway (IH) 12 corridor in Baton Rouge is represented in a GIS; GPS tracks the position and travel times of the floating cars. This data is loaded into the GIS, which is able to compute the average speed for each segment of the corridor, and to represent it in a map form (Bullock et al. 1996, 2).

Transportation corridor and route planning are other applications for which GIS is well-suited. Researchers at Utah State University used GIS to plan optimal demand-response transit routing and scheduling for users with disabilities. The geographic information was based upon Bureau of the Census Topographically Integrated and Geographic Encoding and Referencing (TIGER) files, supplemented by survey data on people with disabilities, and on a geographic representation of the roadway network. Alternate buffering algorithms for determining the number of people within a certain distance of route options were used to determine vehicle routing and scheduling plans (Javid et al 1994, 45).

GIS was used to study the impacts of two highway corridors in North Carolina. The IH 40 corridor connecting Raleigh to the port city of Wilmington and the Carolinas Parkway outer loop around Charlotte were both evaluated with a GIS analysis based on points (cities and other nodes), links (the roadway links), and areas (bordering areas surrounding the GIS features). Impacts of the roadways on economic activity and commuting patterns were assessed, and the researchers concluded that the GIS approach, while it sometimes sacrificed accuracy and statistical rigor, was fast, efficient in its data management, and quite compelling in its ability to coordinate and display impacts and patterns (Hartgen and Li 1994, 64).

A study of two counties in Virginia evaluated the applicability of GIS to pavement management systems, and proposed a basic methodology for application of GIS to transportation management systems in general (Johnson and Demetsky 1994, 67). The methodology recommends identifying the objectives of the management system, assembling the geographic and attribute data required, and configuring the GIS to use the data to meet the objectives. This methodology is related in its basic mission to this proposal for the NTS, although on a smaller scale.

COMPONENTS OF A GIS FOR THE NTS

The way that the different part of the NTS fit together must now be addressed. This relates to the discussion of "layers" by Southworth in his report on the National Transportation Network Analysis Capability. These layers are the manifestation of the linked relational data tables that contain the geographic and attribute data of the NTS. The discussion of the components of the NTS GIS will use Southworth's terminology and description as a starting point, but will not discuss them in more detail as they are relevant to the measures and methodology proposed here.

The first layer is the facilities layer, the one that contains the actual geographic data tables describing the location of the links, nodes, and borders in terms of an x, y coordinate system. This layer should also contain identifying data such as the route number of a highway, or the name of a port. It should, of course, contain identifying information in terms of a unique identification code for the link or node that allows it to be connected to the other data tables of the other layers, which also all contain the appropriate identification codes. The facilities layer will also contain such basic information as the length of a link, and the physical nature of the facility, such as whether it is a roadway or railway facility. The facilities layer will be based upon the geographic information contained in the National Transportation Atlas Databases; the data for the other layers is to be found in the sources cited in the previous chapter on NTS data sources.

This facilities layer is the only one that has a truly hierarchical relationship with the other layers. All the other layers refer to the geographic network of the facilities layer, which may be considered to exist above the other layers. However, although these other layers may refer to each other, they do not do so in a hierarchical manner; none of these other layers is directly dependent upon any other layer.

The next layer to be considered is the services layer. This layer contains data on the transportation services available on given portions of the physical network. It is here that it may become clear that different modes are available on the same facilities, such as passenger rail and freight rail using the same right-of-way, or automobile traffic and motor freight using the same highways. The services layer will contain such information as facility type, i.e. functional class of roadway, or type of rail service and user. It will also contain capacity information, in the form of vehicles per hour, passengers per hour, or tons per hour capability of a facility or system.

Another critical function of the services layer is the defining and tracking of connectivity. The way in which the transportation elements of the facilities layer connect with each other, both within the same mode and between different modes, must be defined in the NTS services layer. This requires specifying whether facilities do connect, how they connect (what type of facility the connector node is, and what services it offers), and the facility-to-facility transfer capacity of the connector node. Most other attribute tables, corresponding to other performance measures, will be able to use existing data, often in GIS format. However, in many cases, the nature and measures of connectivity will have to be constructed specifically for the NTS.

The flows layer will naturally contain volume and output data. This layer may be divided into various attribute tables for different aspects of flow, such as annual flows, average daily flows, and peak hour flows. This layer can contain most of the mobility performance measures: volumes, v/c ratios, congestion, speeds, travel time, delay time, total output, passengers or tons moved through the facility or system per hour.

The "background layer" cited by Southworth, could here be considered either a single layer consisting of several attributes, or several layers of attributes; it does not matter since these layers are not hierarchical. Essentially, other attribute tables will be required for the remaining performance measures: cost-effectiveness, energy consumption, emissions, natural resource impact, safety, economic and employment impact, and such land use-related GIS measures as accessibility, noise impact, and neighborhood impact.

Due to dynamic segmentation, these layers can be constructed at the level of detail appropriate to the nature of their data and its degree of aggregation. Cost-effectiveness measures will be assigned to segments of systems upon which the money has been spent, and from which benefits can be determined in terms of outputs. For the most part, these segments will correspond to links or nodes of the transportation network, such as segments of highway or railway, or to ports. When necessary, the cost-effectiveness segments can be subsets or combinations of facilities.

Measures of safety will correspond for the most part to discrete incidents associated with points on the network. These can be points along links or at nodes. Energy consumption and emissions measures will most likely be constructed in a top-down manner, based on data on flows and congestion. Therefore, the organization and segmentation of the attribute layers for these measures should correspond to that of the flows layer, with its supporting data. Measures of natural resource impact will also mostly correspond to links and nodes, but in some cases will correspond to points, such as designed drainage points. Measures of economic and employment impact will generally be felt on a more aggregate, regional basis. These measures could be prorated and divided by facility and node, but such a division may not be very meaningful. These measures may therefore be left at a more aggregate level.

The remaining measures of accessibility, noise impact, and neighborhood impact are dependent upon the capabilities of GIS not only for display and analysis, but also for their very computation. The previous attribute layers were based upon data tables applied to the GIS. The measures of accessibility, noise impact, and neighborhood impact must be calculated through GIS-based routines for land use "buffering," or analysis of the characteristics of the land uses surrounding a certain map feature. For example, these measures may require the determination of the population within two miles of a highway, or within a mile of an airport. Determination of such measures requires GIS analysis of the geographic representation of the transportation network in the form of the National Transportation Atlas Databases, overlaid with geographic land use data available from the Bureau of the Census. Determination of total route accessibility, in terms of times or distances from an origin to a final destination, requires further GIS capability in the form of path-building and path selection algorithms.

NTS OBJECTIVES AND GIS ANALYTICAL TOOLS

This section will discuss how some of the analytical tools and capabilities of GIS packages can be used to address and meet the objectives of the NTS that were specified in the previous chapter. Some of these tools, such as buffering routines for capturing information about land uses within a certain distance of map features, are basic GIS capabilities. Others will require specially-written utilities, but are nonetheless made possible by the use of GIS data format and capabilities. The needs for these special utilities should be carefully evaluated, and they should be created in a standard format to allow their application to various circumstances.

System Monitoring, Identification of Weaknesses

The application and implications of GIS for the various measures with respect to discrete transportation facilities was discussed in a previous chapter on the features of GIS that make it applicable to the NTS. This section is more concerned with monitoring and evaluation of performance in more of a system-wide context. This requires that the GIS database be able to connect the components of the NTS network.

At the most basic level, the NTS GIS must be able to build trips, full routes from an origin to a destination. Since the NTS will only include major transportation facilities, these origin-destination routes will be somewhat truncated, and macroscopic in scale. These trips will be based upon various travel surveys, such as the Bureau of the Census travel survey, the Commodity Flow Survey (CFS), the Nationwide Passenger Transportation Survey (NPTS), and the American Travel Survey (ATS), which tracks passenger trips over 100 miles long.

In order to do this, the NTS GIS must be able to recognize the combination of network links, both within a single mode and in various modes, that will enable a user to get from an origin to a destination. This requires connectivity information for the connecting nodes, and it also requires an algorithm for identifying a chain, or chains, of links and nodes that can accomplish the desired trip.

In addition to building these routes, the NTS GIS must be able to evaluate them. Once it is able to build, for example, five different chains of links and nodes for accomplishing a given origin-to-destination trip, it must be able to prioritize them based on their performance. It can do this through a consideration of the performance of the different links and nodes, and their overall combination into a trip chain, with respect to the proposed performance measures. In order to evaluate the performance of the network for a given chain, the performance of each component of the chain must be described as fully as possible, which emphasizes the need for as complete a set of data as possible for all NTS components.

To prioritize these trips based on their overall performance, the NTS must be equipped with utilities for multi-criteria evaluation, making trade-offs between the various criteria that form the basis of the proposed performance measures, such as trip time, cost-effectiveness, safety, accessibility of land uses to the facility, and other measures. The NTS must be able to do this both for measures which can be combined between different links and connecting nodes for a given trip, as well as for measures which cannot be combined.

This trip-building routine will give a picture of the flows of passengers and goods, and the transportation facilities that they use. It also can help show the facilities that they do not use or are constrained in using. The NTS can be equipped with capabilities for identifying chains in which one or a few components, either links or nodes, severely diminish the performance of that trip. These components represent weaknesses in the network, whether they are bottlenecks in capacity or facilities that are highly unsafe and represent a risk to the user.

The buffering utility of GIS could also be used to identify transportation facilities within a certain distance of a network link or node that are not connected to the network, but which satisfy certain performance and accessibility criteria that make it a candidate for connection to the link or node in question. Such a situation offers an opportunity for improving system performance through making network connections whose value might only be recognized through the use of GIS.

Another GIS capability which must be used to monitor the NTS is the creation of polygons to define areas for analysis. Geographic boundaries may be defined by a series of links and nodes to enclose the area which is to be analyzed. This area can be defined narrowly, for an urbanized area or even a subsection of an urbanized area, or much more widely, on a state, multi-state, or even national scale. A GIS is capable of spanning such a wide range of scales of focus, from the link-level to the national. However, in order to do so, it must be equipped with utilities for "collapsing" finely detailed elements into more macroscopic elements for wider analyses (Southworth 1995, 11). An example of this would be combining eight intercity links of the same interstate highway into a single link.

This polygon areas will allow the evaluation of certain measures that are less applicable to assignment to specific links and nodes, such as air quality, natural resources impact, and overall accessibility, which can be expressed in terms of a number or percentage of population within a certain time or distance of a certain land use, or other similar measures.

The polygons can also provide an area-wide perspective on the trip chains formed of the links and nodes connecting origins and destinations. In this way, the various weaknesses and obstacles to performance can be reviewed, and evaluated to detect patterns. More successful, better-performing trips can also be reviewed to assess patterns among them. These area-wide patterns can be used to draw conclusions about the causes and effects of good transportation performance and bad performance. These conclusions can in turn be used to inform transportation policy-making.

Address National Goals and Problems

This objective of the decision-making framework builds upon the analysis and conclusions of the first objective, for monitoring the network and detecting problems and weaknesses. In this component, policy alternatives for addressing the deficiency must be formulated and evaluated, and the best alternative must be recommended for adoption.

Through its search for patterns among network weaknesses, the network monitoring will hopefully reveal the nature of the problem. Through its evaluation of network strengths, the network monitoring may also suggest some possible policy alternatives for addressing the problem. In any case, transportation policy-making experience will complement or satisfy the need for viable alternatives.

The evaluation of the various alternatives will require the comparison of performance of various future scenarios. A given scenario will be forecast based on a certain policy option. These are broad, national-level policy decisions, and will require assumptions about their impact on the transportation network. For instance, assumptions must be made about how a policy decision on changing the level of federal matching funds from 80% to 90% for a given transportation fund would impact the infrastructure in a given region.

Other components will also be involved in these forecasts. These include projections of population, land use, transportation demand, and transportation costs. A variety of models may be used to make these projections, ranging from sketch planning models to the full, four-step urban transportation planning process (UTPP).

The NTS GIS can then be configured to reflect the transportation infrastructure resulting from the different policy alternatives, and loaded based on the projections of future conditions surrounding the transportation system. The NTS can then forecast the performance of the network for the various policy alternatives. These performances can be evaluated based on some multi-criteria model, and a preferred solution can be selected.

Progress Toward Performance Targets

In assessing progress toward performance targets, the NTS GIS must simply track performance over time, as well as the performance targets. These different values for performance may be attached to various transportation facilities and systems as different attribute tables.

The NTS GIS should track performance over time as a function of its routine monitoring. In cases in which DOT has entered a performance agreement with some transportation funding recipient, these targets must be set for the appropriate level of aggregation. This entails enclosing the area in question within a polygon and evaluating performance for the overall system, or part of the system in question. Since these performance targets are likely to involve outcomes of the use of the transportation system, these values for overall performance can be more easily aggregated, usually by adding together the impacts of the system components in question.

Support State and MPO Planning

In the context of GIS evaluation of the NTS, federal support of state and MPO transportation planning will mostly be in the form of providing interested states and MPOs with the GIS utilities and tools that DOT develops for use with the NTS. Likewise, DOT should use any available state or MPO GIS utilities that can aid it in developing tools for use with the NTS, and act as a clearinghouse for providing these utilities to other interested states and MPOs.

SUPPORTING TECHNOLOGIES FOR THE NTS

The most important technologies for supporting the NTS are Intelligent Transportation System (ITS) technologies and those related to ITS. ITS is based on the concept of using advanced information, communication, and control technologies to improve the efficiency of the nation's transportation network and reduce its negative impacts (ITS America 1994, i).

Although ITS encompasses many systems serving many objectives. Primary components include travel and transportation management supported by real-time information, travel demand management, public transportation operations, electronic payment services, commercial vehicle operations, incident and emergency response management, and advanced vehicle control systems (ITS America 1994, 12). The goals of these measures are primarily short-term: improved travel flows, more efficient use of the system, and mitigation of negative impacts. However, in order to accomplish these goals, extensive transportation system monitoring and data collection are required, in many of the same goal areas as the NTS. It is here that the NTS can realize a collateral benefit of ITS, by using the data that is collected for ITS programs.

Furthermore, ITS is being developed in the form of a nationwide architecture in order to make all of its components and systems compatible, so that, for example, an automobile traveling across the country can use its toll tag or navigation computer with all local ITS systems. Such a nationwide architecture will result in consistent data format for ITS-collected data, facilitating its adaptation to the NTS. The following is a discussion of the ways that ITS operations can support NTS data and performance measures.

Improved mobility is clearly a central goal of ITS, and will involve monitoring and data collection that support the NTS. Information on highway passenger vehicle flows and volumes will be tracked by magnetic loop detectors or some similar monitoring device. This data will yield measures of vehicle volume and facility output. Flow and volume measures for other passenger modes will also be aided by ITS. Transit mode flows can be tracked through transit riders' use of electronic payment services, in such forms as electronically encoded smart cards. These cards can be used to track detailed passenger origin and destination data, and give a very complete picture of flows. In a similar manner, electronic payment in the form of electronic toll tags and other electronic automobile identification can be used to track roadway origin and destination information.

Freight flows and volumes can be monitored through ITS commercial vehicle operations. In the freight sector, shipments in all modes can be electronically marked with transponders containing information on weight, commodity, origin and destination, and other information, which can be read by monitors along transportation corridors and at connecting nodes, such as highway interchanges or intermodal terminals.

Obviously, a great deal of this information, especially on the freight side but also in the passenger sector, is sensitive and its use raises concerns among system users. Privacy is a central concern of ITS implementation, and is addressed through such measures as encryption of freight transponder signals and restricted access to certain information. The NTS will preserve transportation system user privacy and anonymity as well, in its use of ITS data as well as in other areas. In the area of ITS data, there are many cases in which the NTS will not even require sensitive information from ITS providers, and can rely on data that is sufficiently aggregate to protect privacy. In other cases in which it does use sensitive data, the NTS can restrict access to this data and release it only in a safely aggregated form.

Other mobility measures required for the NTS, such as speeds, travel times, congestion, and delay will also be tracked for ITS purposes. These measures can be made more robust than they are currently through the use of ITS technologies. Global Positioning Systems (GPS), satellite-based systems that can give accurate location of a signal source, can be used to track to track the positions of electronically marked vehicles over time, generating measures of speed and travel time, and identifying points of congestion and delay. For the highway passenger mode, these measures can be tracked through the use of specially tagged vehicles; these can be public vehicles, or they can be private vehicles that participate voluntarily. For freight modes and other passenger modes, such as transit, air, and rail, all vehicles can be marked and monitored. A great advantage of using GPS to track these measures is its ease of use compared to more conventional speed and travel time monitoring methods, such as "floating car" highway monitoring. These GPS-tracked vehicles will simply be collecting data passively during the normal course of their operation.

Connectivity measures can also be supported by ITS data. Major functions of ITS include route guidance and route selection assistance. This is to be provided to drivers, motor freight operators, transit users, and intermodal trip-makers. This could also be implemented for freight shippers. In order to supply this information, the ITS providers must have data on the nodes connecting the links of the transportation system, for both connectors in a single mode and intermodal connectors. To make decisions on routing recommendations, data on connectors would have to include the transfer capacity of these connectors, in addition to information about facilities and modes served. This data would be useful for NTS connectivity measures.

NTS environmental measures would be aided by improved field monitoring undertaken for ITS. The air quality regulations under the CAAA require that transportation network and management decisions made for ITS decision support must take air quality into account. This means that ITS providers must undertake increased air quality and emissions monitoring. The resulting improved field data will enable finer calibration and better accuracy for air quality and emissions models that are currently in use. ITS tracking of vehicle flows, speeds, congestion, and delay can also improve measures of transportation fuel consumption.

Safety measures will also be supported by ITS monitoring. Incident detection and response is a central component of ITS operations due to the major part that incidents play in congestion and delay. Safety and incident data are currently monitored and collected in detail. However, ITS safety and incident data does offer potential improvement over current tracking methods in the form of faster and easier data processing. Because the ITS initiative calls for a national architecture, ITS data systems will be more compatible, and data transfer will be faster and easier. The ITS data will probably not capture all incidents, especially not those on minor transportation corridors. However, it may offer more timely data on safety and incidents on the major facilities that are the focus of NTS monitoring.

ITS technologies therefore offer the NTS a rich source of data. ITS may in fact be too rich a source of data, in the sense that it collects more data for its real-time transportation decision support than the NTS can use for its policy-oriented performance evaluation. This should be kept in mind, and ITS data should be carefully cleaned and compressed to provide the NTS with only the data that it truly needs, without overwhelming the system or obscuring the trends, patterns, and problems that it is designed to detect.

SUMMARY

The mapping, data storage, data analysis, and display capabilities of GIS make it an ideal platform for the NTS. At its most basic level, the NTS, like any other transportation database, must be represented by a map. GIS is able to use geographic data for the transportation network to map it. A GIS platform can also attach the great volume of data and performance measures to the various geographic components of the network. More importantly, however, a GIS platform can be used to analyze the network through path-building, buffering, polygon area analysis, and other utilities, in order to aid in pursuing the policy objectives of the NTS. The growing predominance of GIS use in transportation planning at all levels, combined with the fact that GIS data can generally be converted from one system to another, will facilitate the gathering of data for the NTS. Therefore, the use of a GIS platform, supplemented by data available from ITS initiatives, can help to make the NTS a feasible and useful policy-making tool.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

This report has proposed a National Transportation System (NTS), pursuant to the requirement issued by Secretary of Transportation Federico Peña in December 1993 and designed to be in accordance with the principals of the ISTEA legislation of 1991. The NTS is designed to monitor the performance of the nation's transportation network in all modes, and to inform transportation policy-making on the national level.

This report has described the various components, functions, and features of such an NTS. It has discussed the legislative and institutional background of the NTS; the goals of the NTS; the set of indicators that the NTS will use as measures of performance; the data sources for supporting these performance measures; a framework for using the performance measures to inform policy-making; and the implications of a GIS platform for the NTS. The following are the conclusions and recommendations that have resulted from this process of investigation and proposal.

CONCLUSIONS

- Traditionally, public sector transportation planning has been modally oriented, and has tended to concentrate on passenger issues more than freight issues.
- Despite the increased transportation planning authority of states and MPOs under ISTEA, DOT still retains critical national policy-making responsibility.
- Improved mode-neutral planning and analysis are necessary to fulfill the multimodal and intermodal objectives of ISTEA, at the federal level as well as at state, regional, and local levels.
- Transportation planning under ISTEA, at all jurisdictional levels, requires the use of performance measures; such measures form the basis of the transportation management systems for the state and MPO levels, and the NTS at the national level.
- Transportation performance must be measured with respect to positive social and economic goals and to negative social, economic, and environmental impacts, in addition to the effectiveness and efficiency of mobility through the transportation network.
- The performance measures are the most critical component of the proposed NTS. These performance measures are based directly upon the goals of the NTS; they reflect the intermodal, user-oriented, and outcome-oriented principles of ISTEA and the NTS; and they serve as the basis for the policy-making framework and GIS platform for the NTS.

- Most data required for supporting the proposed performance measures is already collected at some level, but is stored with many different agencies and in different formats.
- Satisfying the data needs of the NTS performance measures is dependent upon the ability to obtain and adapt data from various sources: localities, MPOs, states, and various federal agencies.
- The mapping, data storage, and data analysis capabilities of Geographic Information Systems (GIS) are well-suited to transportation applications.
- GIS and its geographic specification of attributes will make borders and boundaries easier to define, and overlapping jurisdictions (states, counties, urbanized areas, localities) easier to manipulate.
- The prevalence of GIS application to transportation databases and analysis systems is increasing, and GIS utilities make data conversion between GIS databases relatively convenient.
-

RECOMMENDATIONS

- DOT should use the NTS as a tool for guiding national transportation policy in an intermodal and unified manner.
- The NTS should be used to consider freight issues and freight planning in conjunction with passenger planning, instead of in separate and unequal contexts.
- The NTS should pursue national transportation goals in the areas of mobility, connectivity, cost-effectiveness, energy efficiency, air quality, natural resources conservation, safety, accessibility, neighborhood integrity, and economic and employment development; the performance measures for the NTS should serve as indicators for these goals.
- Great care and time should be taken in specifying the NTS performance measures and in adapting data to them, since the performance measures are the key to successful implementation of the NTS.
- The performance measures for the NTS should be as consistent as possible across different modes, and for intermodal connections.
- Available sources of data should be used to support these performance measures whenever possible.
- Uniformity of data from states, MPOs, and localities for use with the NTS should be encouraged, but not required.

- The NTS should use a GIS of the nationwide transportation network, comprising both geographic location data and performance-oriented attribute data, as the platform for its data storage and analysis needs.
- The NTS should be an opportunity and an agent of increasing the usage of GIS for transportation databases, and of encouraging greater uniformity in these GIS databases.
- The NTS should use its performance measures to pursue national transportation goals by monitoring the nation's transportation network, addressing problems in the national transportation network, measuring progress toward performance targets, and aiding state and MPO transportation planning.
- Further research into performance evaluation under the NTS should focus in the short term on finalizing performance measures, establishing data procurement protocols for obtaining the data necessary to support the performance measures, and adapting the data to the performance measures, especially for GIS databases. Longer term objectives of NTS research should involve creating the "State of the Transportation System" monitoring report, testing the usefulness of the NTS in guiding transportation policy, and evaluating the effectiveness of the NTS in doing so.

ISTEA offers the potential for conducting transportation planning in a more multimodal and intermodal environment. This report proposes an NTS that is designed to help realize this potential by analyzing transportation performance in a unified system that encompasses the performance of the various modes on a national scale. Such an analytical capability will enable more informed, intermodal, performance-oriented transportation policy-making.

APPENDIX

HIGHWAY DATA

Table A.1 Austin Highways - Loop 1 (Mopac)

South *North*	Wm Cannon to Loop 360	Loop 360 to Enfield Rd.	Enfield Rd. to FM 2222	FM 2222 to Rt. 183	Rt. 183 to Wells Brnch
Outputs					
Mobility					
Avg. Daily Volume	10,880	122,140	148,830	138,600	74,510
Daily Capacity	112,500	112,500	112,500	112,500	112,500
V/C Ratio	0.10	1.09	1.32	1.23	0.66
Link Length (miles)	2.9	3.6	3.5	3.2	5.2
Min Peak Spd (mph) AM	2 (NB)	13 (NB)	48 (SB)	14 (SB)	28 (NB)
Min Peak Spd (mph) PM	14 (NB)	18 (SB)	14 (NB)	51 (NB)	10 (NB)
Speed (mph): 24 hr Avg.	55.0	55.0	55.0	55.0	55.0
Travel Time (min): 24 hr	3.16	3.93	3.82	3.49	5.67
Facility Usage					
VMT per day	31,552	439,704	520,905	443,520	387,452
Output (Veh/hr): 24 hr	453	5,089	6,201	5,775	3,105

Sources: Austin Transportation Study (ATS) 1993 volume and capacity database.
City of Austin 1995 congestion management travel time data.

Table A.2 Austin Highways - Rt. 183

South *North*	South of Rt 71	Rt 71 to MLK	MLK to Rt 290	Rt 290 to IH 35	IH 35 to Rt 1325	Rt 1325 to Lp 1	North of Lp 1
Outputs							
Mobility							
Avg. Daily Volume	18,280	54,370	42,560	42,560	69,590	82,870	102,790
Daily Capacity	29,000	43,500	29,000	43,500	43,500	43,500	43,500
V/C Ratio	0.63	1.25	1.47	0.98	1.60	1.91	2.36
Link Length (miles)	2.3	5.4	3.1	1.8	3.0	0.8	0.9
Speed (mph): 24 hr Avg.	33.8	33.8	33.8	33.8	33.8	33.8	33.8
Travel Time (min): 24 hr	4.08	9.59	5.50	3.20	5.33	1.42	1.60
Facility Usage							
VMT per day	42,044	293,598	131,936	76,608	208,770	66,296	92,511
Output (Veh/hr): 24 hr	762	2,265	1,773	1,773	2,900	3,453	4,283

Sources: Austin Transportation Study (ATS) 1992 volume and capacity database.
City of Austin 1993 congestion management travel time data.

Table A.3 Dallas Highways - IH 35 E

South / *North*	South of IH 20	IH 20 to Rt. 67	Rt. 67 to IH 30	IH 30 to Rt. 114	Rt. 114 to Rt. 12	Rt. 12 to IH 635	North of IH 635
Outputs							
Mobility							
Avg. Daily Volume	85,000	81,000	155,000	217,000	128,000	211,000	160,000
Daily Capacity	112,500	112,500	112,500	112,500	112,500	112,500	112,500
V/C Ratio	0.76	0.72	1.38	1.93	1.14	1.88	1.42
Link Length (miles)	4.3	4.6	5.1	4.7	4.5	2.3	5.5
Facility Usage							
VMT per day	365,500	372,600	790,500	1,019,900	576,000	485,300	880,000
Output (Veh/hr): 24 hr	3,542	3,375	6,458	9,042	5,333	8,792	6,667

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.

Table A.4 Dallas Highways - IH 30

West / *East*	Rt. 360 to Rt. 12	Rt. 12 to IH 35 E	IH 35 E to Rt. 80	Rt. 80 to IH 635	East of IH 635
Outputs					
Mobility					
Avg. Daily Volume	86,000	114,000	152,000	91,000	87,000
Functional Capacity	112,500	112,500	112,500	112,500	112,500
V/C Ratio	0.76	1.01	1.35	0.81	0.77
Link Length (miles)	8.0	6.1	6.9	3.2	6.7
Facility Usage					
VMT per day	688,000	695,400	1,048,800	291,200	582,900
Output (Veh/hr): 24 hr	3,583	4,750	6,333	3,792	3,625

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.

Table A.5 Houston Highways - IH 45

South *North*	Galv. Co. to Airport Blvd	Airport Blvd to IH 610	IH 610 to Rt. 59	Rt. 59 to IH 10	IH 10 to IH 610	IH 610 to Rt. 8
Outputs						
Mobility						
Avg. Daily Volume	177,000	222,000	189,000	187,000	179,000	214,000
Daily Capacity	112,500	112,500	112,500	112,500	112,500	112,500
V/C Ratio	1.57	1.97	1.68	1.66	1.59	1.90
Link Length (miles)	14.5	3.6	6.1	2.3	3.9	10.0
Speed (mph): 24 hr Avg	54.3	54.3	54.3	54.3	54.3	54.3
Peak Avg	46.3	46.3	46.3	46.3	46.3	46.3
Travel Time (min):24 hr	16.0	4.0	6.7	2.5	4.3	11.0
Peak	18.8	4.7	7.9	3.0	5.1	13.0
Facility Usage						
VMT per day	2,566,500	799,200	1,152,900	430,100	698,100	2,140,000
Output (Veh/hr): 24 hr	7,375	9,250	7,875	7,792	7,458	8,917

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1994 speed data.

Table A.6 Houston Highways - Rt. 59

South *North*	South of Gessner	Gessner to IH 610	IH 610 to Rt. 288	Rt. 288 to IH 10	IH 10 to IH 610	IH 610 to L York	L York to Rt. 8
Outputs							
Mobility							
Avg. Daily Volume	126,000	244,000	221,000	140,000	118,000	127,000	94,000
Daily Capacity	112,500	112,500	112,500	112,500	112,500	112,500	112,500
V/C Ratio	1.12	2.17	1.96	1.24	1.05	1.13	0.84
Link Length (miles)	2.4	8.7	6.1	3.9	4.0	4.4	5.6
Speed (mph):24 hr Avg.	55.9	55.9	55.9	55.9	55.9	55.9	55.9
Peak Avg.	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Travel Time (min):24 hr	2.6	9.3	6.5	4.2	4.3	4.7	6.0
Peak	2.9	10.4	7.3	4.7	4.8	5.3	6.7
Facility Usage							
VMT per day	302,400	2,122,800	1,348,100	546,000	472,000	558,800	526,400
Output (Veh/hr): 24 hr	5,250	10,167	9,208	5,833	4,917	5,292	3,917

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1994 speed data.

Table A.7 Houston - Dallas-Fort Worth Intercity Highway - IH 45

South *North*	Rt. 1960 to Rt. 105	Rt. 105 to Rt. 150	Rt. 150 to Rt. 30	Rt. 30 to Rt. 21	Rt. 21 to Rt. 7	Rt. 7 to Rt. 79
Outputs						
Mobility						
Avg. Daily Volume	110,000	38,000	33,000	18,800	18,500	18,000
Functional Capacity	112,500	75,000	75,000	75,000	75,000	75,000
V/C Ratio	0.98	0.51	0.44	0.25	0.25	0.24
Link Length (miles)	20	17	14	26	22	15
Facility Usage						
VMT per day	2,200,000	646,000	462,000	488,800	407,000	2,200,000
Output (Veh/hr): 24 hr	4,583	1,583	1,375	783	771	4,583

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1994 speed data.

Table A.8 San Antonio Highways - IH 37 / Rt. 281

South *North*	Rt. 1604 - Rt. 181	Rt. 181 - IH 410	IH 410 - Rt. 90	Rt. 90 to IH 35	IH 35 to Hildebrand	Hildebrd to IH 410	IH 410 to Rt. 1604
Outputs							
Mobility							
Avg. Daily Volume	18,600	34,000	54,000	122,000	116,000	97,000	127,000
Daily Capacity	75,000	75,000	112,500	112,500	112,500	112,500	112,500
V/C Ratio	0.25	0.45	0.48	1.08	1.03	0.86	1.13
Link Length (miles)	3.1	1.8	6.3	3.1	2.4	4.5	7.4
Speed (mph):24 hr Avg.	54.4	54.4	54.4	54.4	54.4	54.4	54.4
Travel Time (min):24 hr	3.42	1.99	6.95	3.42	2.65	4.96	8.2
Facility Usage							
VMT per day	57,660	61,200	340,200	378,200	278,400	436,500	939,800
Output (Veh/hr): 24 hr	775	1,417	2,250	5,083	4,833	4,042	5,292

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1994 speed data.

Table A.9 San Antonio Highways - IH 410

Clockwise from North	Rt. 281 to IH 35	IH 35 to Gibbs	Gibbs to IH 10	IH 10 to Rt. 87	Rt. 87 to IH 37
Outputs					
Mobility					
Avg. Daily Volume	165,000	133,000	56,000	45,000	33,000
Daily Capacity	112,500	112,500	75,000	75,000	75,000
V/C Ratio	1.47	1.18	0.75	0.60	0.44
Link Length (miles)	5.4	3.3	2.9	2.6	5.0
Speed (mph): 24 hr Avg.	54.4	54.4	54.4	54.4	54.4
Travel Time (min): 24 hr	5.96	3.64	3.20	2.87	5.5
Facility Usage					
VMT per day	891,000	438,900	162,400	117,000	165,000
Output (Veh/hr): 24 hr	6,875	5,542	2,333	1,875	1,375

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.
Texas Natural Resources Conservation Commission (TNRCC) 1994 speed data.

Table A.10 San Antonio - Houston Intercity Highway - IH 10

West East	Rt. 1604 to Rt. 1518	Rt. 1518 to Rt. 123	Rt. 123 to Rt. 80	Rt. 80 to Rt. 77	Rt. 77 to Rt. 71	Rt. 71 - Rt. 36	Rt. 36 to Rt. 6
Outputs							
Mobility							
Avg. Daily Volume	29,000	24,000	18,700	15,400	17,300	24,000	48,000
Daily Capacity	75,000	75,000	75,000	75,000	75,000	75,000	75,000
V/C Ratio	0.39	0.32	0.25	0.21	0.23	0.32	0.64
Link Length (miles)	5	19	17	46	22	24	33
Facility Usage							
VMT per day	145,000	456,000	317,900	708,400	380,600	576,000	1,584,000
Output (Veh/hr):24 hr	1,208	1,000	779	642	721	1,000	2,000

Sources: Texas Department of Transportation (TxDOT) 1994 traffic volume data.

Table A.11 San Antonio Roadways - Aggregate Measures

Outputs		
Mobility		
System Usage		
VMT per day		30,523,690
Delay: Total Vehicle Hours per day		72,000
Delay per VMT (min)		0.14
Cost-Effectiveness		
Capital Cost per year	$	134,772,141.50
Net Facility Cost per 1000 VMT	$	12.10
Outcomes		
Environmental		
Air Quality		
Total Emissions		
NO x (tons per day)		90.9
VOC (tons per day)		75.5
CO (tons per day)		613.6
Emissions per VMT		
NO x (lbs per 1000 VMT)		5.95
VOC (lbs per 1000 VMT)		4.94
CO (lbs per 1000 VMT)		40.21
Natural Resource Impact		
Social		
Safety		
Accidents / Incidents per year		37,444
Fatalities per year		114
Injuries per year		25,580
Accidents per Million VMT		3.36
Fatalities per Million VMT		0.01023
Injuries per Million VMT		2.30
Economic		
Employment Impact: Construction Jobs		1,067

Sources: TNRCC 1993 congestion and air quality management data.
TxDOT 1994-1995 project cost data.
Texas Department of Public Safety (DPS) 1994 motor vehicle accident data.
BTS: 1992 urbanized areas delay data.
FHWA: 1991 Highway Statistics.

AIR DATA

Table A.12 Austin Airport

	Austin Robert F. Mueller Airport
Outputs	
Mobility	
Volume (per year)	
Enplaned Passengers	2,268,486
Enplaned Tons - Freight	19,425.50
Enplaned Tons - Mail	4,159.90

Source: 1993 Airport Activity Statistics of Certificated Route Air Carriers.

Table A.13 Dallas Airports

	Dallas - Fort Worth International Airport (DFW)	Dallas Love Field (DAL)
Outputs		
Mobility		
Volume (per year)		
Enplaned Passengers	24,655,922	3,197,237
Enplaned Tons - Freight	191,252.55	5,167.59
Enplaned Tons - Mail	104,000.48	1,509.79

Source: 1993 Airport Activity Statistics of Certificated Route Air Carriers.

WATER CARRIER DATA

Table A.14 Port of Galveston

Outputs	
Mobility	
Volume (tons per year)	9,755,324
Domestic	3,808,241
Foreign	5,947,083
Imports	1,428,360
Exports	4,518,723
Facility Output (tons/hr)	1,114
Outcomes	
Environmental	
Air Quality	
Total Emissions	
NO x (tons/day)	0.509
VOC (tons/day)	0.101
CO (tons/day)	0.065
Emissions per PMT	
NO x (tons/million tons cargo)	19.04
VOC (tons/million tons cargo)	3.77
CO (tons/million tons cargo)	2.43
Natural Resource Impact	
Pollution Incidents per year	166
Incidents per Million Tons	17.0
Social	
Safety	
Accidents / Incidents per year	
Allisions, collisions	91
Fires, explosions	4
Casualties	56
Deaths	1
Rates per Million Tons	
Allisions, collisions	9.328
Fires, explosions	0.410
Casualties	5.740
Deaths	0.103

Sources: U.S. Army Corps of Engineers Waterborne Commerce Statistics Center (WCSC) 1993 port tonnage data.
U.S. Coast Guard 1993 pollution and safety data.
TNRCC 1994 emissions data.

TRANSIT DATA

Table A.15 Dallas Area Rapid Transit (DART) System

	Motor Bus	Demand Response	Total
Outputs			
Mobility			
Volume (pax trips)	48,250,100	925,200	49,175,300
Capacity (pk hr veh)	530	312	842
Average Speed (mph)	14.26	14.65	14.38
System Usage			
Revenue Vehicle Hrs	1,291,600	553,900	1,845,400
Revenue VMT	18,420,900	8,117,100	26,538,000
PMT	170,065,700	9,687,100	179,752,800
System Output			
Trips / System Hr	7,344	141	7,485
Trips / Rev Veh Hr	37.36	1.67	26.65
Cost-Effectiveness			
Capital Cost	$ 16,494,900.00		$ 16,494,900.00
Operating Cost	$ 129,041,100.00	$ 13,315,600.00	$ 142,356,700.00
Total Cost	$ 145,536,000.00	$ 13,315,600.00	$ 58,851,600.00
Revenues			
Passenger Fares			$ 20,641,721.50
Total Direct Op Revs			$ 139,509,566.00
Outcomes			
Environmental			
Energy Efficiency			
Diesel Fuel (gal)	6,859,900		
CNG (lbs)	70,000		
Total Energy (Btus)	952,906,700,000		
Intensity (Btus/PMT)	5,603		
Social			
Safety			
Accidents / Incidents	450		
Fatalities	1		
Injuries	746		
Rates per Million PMT			
Accidents/Incidents	2.646		
Fatalities	0.006		
Injuries	4.387		

Source: Federal Transit Administration (FTA) Section 15 data.

Table A.16 Galveston - Island Transit System

	Motor Bus	Light Rail	Demand Resp.	Total
Outputs				
Mobility				
Volume (pax trips)	1,082,100	107,000	24,300	1,213,400
Capacity (pk hr veh)	14	3	2	19
Average Speed (mph)	11.94	4.64	9.66	11.02
System Usage				
Revenue Vehicle Hrs	37,900	4,200	5,900	48,000
Revenue VMT	452,600	19,500	57,000	529,100
PMT	3,179,700	240,800	128,900	3,549,400
System Output				
Trips / System Hr	165	16.3	3.70	185
Trips / Rev Veh Hr	28.55	25.48	4.12	25.28
Cost-Effectiveness				
Capital Cost	$ 134,100.00	$145,700.00		$ 279,800.00
Operating Cost	$1,328,500.00	$283,800.00	$123,800.00	$1,736,100.00
Total Cost	$1,328,500.00	$429,500.00	$123,800.00	$2,015,900.00
Revenues				
Passenger Fares				$ 494,228.40
Total Direct Op Revs				$ 536,895.60
Outcomes				
Environmental				
Energy Efficiency				
Diesel Fuel (gal)	146,200	7,200	4,600	158,000
CNG (lbs)	528,000			528,000
Electric (kWhr)			4,100	4,100
Total Energy (Btus)	31,128,868,000	998,640,000	652,009,200	32,779,517,200
Intensity (Btus/PMT)	9,790	4,147	5,058	9,235
Social				
Safety				
Accidents / Incidents	25	1	7	33
Fatalities	0	0	0	0
Injuries	6	0	0	6
Rates per Million PMT				
Accidents/Incidents	7.862	4.153	54.306	9.297
Fatalities	0.000	0.000	0.000	0.000
Injuries	1.887	0.000	0.000	1.690

Source: Federal Transit Administration (FTA) Section 15 data.

REFERENCES

Bloom, Madeleine S. 1993. Data for Policy Use: The Impacts of ISTEA on Data Collection. *Transportation Data Needs: Programs for a New Era: Implications for State DOTs and MPOs: Proceedings of a Conference*. Transportation Research Circular 407. National Academy Press. 41-44.

Bradley, Kathleen. Bureau of Transportation Statistics (BTS), U.S. Department of Transportation (DOT). 1995. *Directory of Transportation Data Sources, 1995.*

Bullock, Darcy, Cesar A. Quiroga, and Chris Schwehm. 1996. Dissemination of Travel Time Information Along Congested Corridors. Unpublished.

Bureau of Transportation Statistics (BTS), U.S. Department of Transportation (DOT). 1994. *National Transportation Statistics, 1995.* U.S. Government Printing Office, Washington DC.

California Department of Transportation, Division of Planning. 1994. Intermodal Transportation Management System: Work Plan. Unpublished.

Cambridge Systematics, Inc. 1995. Compendium of Preliminary Performance Measures for the National Transportation System. Unpublished.

Central Transportation Planning Staff of the Boston Metropolitan Planning Organization. 1994. ISTEA Management System Guidebook for States and MPOs. Unpublished.

Clymer, Brian W. 1993a. ISTEA: A Look Back at Year One. *Public Transportation Decisionmaker.* U.S. Conference of Mayors, Washington DC. Vol. 1, No. 1: 4-5.

———. 1993b. New Dimensions in Transportation Planning. *Moving Urban America: Proceedings of a Conference*. Transportation Research Board Special Report 237. National Academy Press, Washington DC. 147-151.

Dahms, Lawrence D. 1993a. Bay Area MPO Takes Advantage of ISTEA Flexibility. *Public Transportation Decisionmaker.* U.S. Conference of Mayors, Washington DC. Vol. 1, No. 1. 10-12.

———. 1993b. Regional Context of Intermodal Decisions. *ISTEA and Intermodal Planning: Concept, Practice, Vision.* TRB Special Report 240. National Academy Press, Washington DC. 130-7.

Davis, Stacy C. 1994. Oak Ridge National Laboratory, for the U.S. Department of Energy (DOE). *Transportation Energy Data Book.*

DeCorla-Souza, Patrick and Ronald Jensen-Fisher. 1994. Comparing Multimodal Alternatives in Major Travel Corridors. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 15-23.

DOT Program Design Work Group. March 1995. Potential Issues Relating to Development of Transportation System Performance Measures for Use by the U.S. Department of Transportation. Unpublished.

Dwyer, Lawrence. 1992. Intermodalism and ISTEA: The Challenges and the Changes. *Public Roads.* FHWA. 4-6.

Dye Management Group, Inc. for the Texas Department of Transportation. November 1993. The Texas Transportation Plan: Partnerships Into the 21st Century. Unpublished.

Federal Highway Administration (FHWA), DOT. 1993a. The National Highway System: The Backbone of America's Intermodal Transportation Network.

———. 1993b. The Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance.

———. 1993c. *Highway Performance Monitoring System Field Manual.*

———. 1995. *Highway Statistics, 1994.*

Florida Department of Transportation. 1994. Implementing Florida's Intermodal Planning Process. Unpublished.

Fuller, John W. 1993. The Road to Intermodalism. *ISTEA and Intermodal Planning: Concept, Practice, Vision: Proceedings of a Conference.* Transportation Research Board Special Report 240. National Academy Press, Washington DC. 113-129.

Hagquist, Ronald F. 1994. High-Precision Prioritization Using Analytical Hierarchy Process: Determining State HPMS Component Weighting Factors. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 7-14.

Hartgen, David and Yuanjun Li. 1994. Geographic Information Systems Applications to Transportation Corridor Planning. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 57-66.

Helton, Jack D. 1993. Data Needs for Management Systems. *Transportation Data Needs: Programs for a New Era: Implications for State DOTs and MPOs: Proceedings of a Conference.* Transportation Research Circular 407. National Academy Press, Washington DC. 23-36.

Hendrix, Allan. 1993. Intermodal Experience of the California Department of Transportation. *ISTEA and Intermodal Planning: Concept, Practice, Vision: Proceedings of a Conference.* Transportation Research Board Special Report 240. National Academy Press, Washington DC. 67-72.

Huerta, Michael, DOT. May 1995. NTS Initiative: Refinements to the Development Process. Unpublished.

Humphrey, Thomas F. 1995. Consideration of the 15 Factors in the Metropolitan Planning Process. *National Cooperative Highway Research Program Synthesis 217.* National Academy Press, Washington DC.

Intelligent Transportation Society of America (ITS America). 1994. *ITS Architecture Development Program.*

Javid, Massoud, Prianka N. Seneviratne, Prabhakar Attaluri, and Jay Aguilar. 1994. Application of Geographic Information Systems in Planning Transit Services for People with Disabilities. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 40-48.

Johnson, Brad H. and Michael J. Demetsky. 1994. Geographic Information Systems Environment for Transportation Management Systems. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 67-73.

Karash, Karla H. and Carol Schweiger. 1994. Identification of Transportation Planning Data Requirements in Federal Legislation. Technology Sharing Program, DOT.

Larson, Thomas D. 1993a. ISTEA: Where Are We After a Year? *Public Roads.* Vol. 56, No. 4.

———. 1993b. Wanted: Pliable Paradigms for Transportation Investment. *Moving Urban America: Proceedings of a Conference.* Transportation Research Board Special Report 237. National Academy Press, Washington DC. 134-146.

Liburdi, Lillian. 1993. The Promise of ISTEA. *ISTEA and Intermodal Planning: Concept, Practice, Vision: Proceedings of a Conference.* Transportation Research Board Special Report 240. National Academy Press, Washington DC. 55-61.

Martinez, Robert. 1993. Perspective from the Office of Intermodalism. *ISTEA and Intermodal Planning: Concept, Practice, Vision: Proceedings of a Conference.* Transportation Research Board Special Report 240. National Academy Press, Washington DC. 47-54.

Massachusetts Institute of Technology Center for Transportation Studies. 1995. NTS: What It Means for the Nation. *Transportation.* No. 34.

Mazur, George D. and Michael D. Meyer. 1995. Performance-Based Transportation Planning: Converting Concept to Practice. For 1995 Meeting of the Transportation Research Board. Unpublished.

Mead, Kenneth M., U.S. General Accounting Office (GAO). 1994. Testimony before the Committee on Environment and Public Works, U.S. Senate. National Highway System: Refinements Would Strengthen the System.

Meyer, Michael D. 1993a. Conference Findings. *ISTEA and Intermodal Planning: Concept, Practice, Vision: Proceedings of a Conference.* Transportation Research Board Special Report 240. National Academy Press, Washington DC. 4-18.

———. 1993b. Data, Data, and More Data: The Foundation to Performance-Based Planning. *Transportation Data Needs: Programs for a New Era.* Transportation Research Circular No. 407. National Academy Press, Washington DC. 9-12.

———. 1993c. Planning: The Challenge of Being the Glue. *Moving Urban America: Proceedings of a Conference.* Transportation Research Board Special Report 237. National Academy Press, Washington DC. 91-113.

National Commission on Intermodal Transportation. 1994. *Final Report: Toward a National Intermodal Transportation System.*

Neumann, Lance A. 1995. Performance Measures: Promise and Pitfalls. Unpublished.

Neumann, Lance A., Frances D. Harrison, and Kumares Sinha. 1993. The Changing Context for Programming. *Transportation Planning, Programming, and Finance.* Transportation Research Circular No. 406. National Academy Press, Washington DC. 50-63.

Nungesser, Lisa G. and Eddie Shafie. 1993. Metropolitan Planning Organizations' Transportation Improvement Programs: Project Selection Procedures. *Fourth National Conference on Transportation Planning Methodologies and Applications*. Jerry M. Faris, Tallahassee FL.

Savonis, Mike. 1994-5. The CMAQ Program: Realizing ISTEA's Promise. *Surface Transportation Policy Project Progress*. Volume IV, No. 10.

Southworth, Frank. 1995. A National Transportation Network Analysis Capability: Issues and Challenges. Unpublished.

U.S. Department of Transportation (DOT). 1994a. The National Transportation System. Unpublished.

———. 1994b. National Transportation System Performance Measures: Statement of Work. Unpublished.

———. 1994c. Putting the Pieces Together: A Working Paper on the Criteria for Identifying the NTS. Unpublished.

U.S. General Accounting Office (GAO): Resources, Community and Economic Development Division. 1993. Transportation Infrastructure: Better Tools Needed for Making Decisions on Using ISTEA Funds Flexibly.

Volpe National Transportation Systems Center and BTS, DOT. 1995. *National Transportation Statistics, 1996*. U.S. Government Printing Office, Washington DC.

Welch, Rupert. 1993. National Highway System Is a Blueprint for ISTEA. *Inside DOT and Transportation Week*. Vol. IV, No. 48.

Weil, Ray. 1995a. NTS Performance Measures: What Are They? What Good Are They? How Will They Be Used? Unpublished.

———. 1995b. Working Report: NTS Performance Measurement Efforts at DOT. Unpublished.

Younger, Kristina E. 1994. Multimodal Project Evaluation: A Common Framework, Different Methods. *Multimodal Priority Setting and Application of Geographic Information Systems.* Transportation Research Record No. 1429. National Academy Press, Washington DC. 24-29.

Younger, Kristina E. and David G. Murray. 1994. Developing a Method of Multimodal Priority Setting for Transportation Projects in the San Francisco Bay Area in Response to Opportunities in ISTEA. *Multimodal Priority Setting and Application of Geographic Information Systems*. Transportation Research Record No. 1429. National Academy Press, Washington DC. 1-6.

Zhang, Zhanmin. 1993. *GIS Applications in Urban Roadway Management Systems*. University of Texas at Austin.