Technical Report Documentation Page

1. Report No. FHWA/TX-07/0-5410-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Developing Freight Highway Corridor Performance Measure Strategies in Texas		5. Report Date August 2006 6. Performing Organization Code
7. Author(s) Robert Harrison, Mike Schofield, Lisa Loftus-Otway, Dan Middleton, and Jason West		8. Performing Organization Report No. 0-5410-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-5410
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Technical Report September 2005–August 2006 14. Sponsoring Agency Code

15. Supplementary Notes
Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

16. Abstract

This one-year scoping study examined the current status of highway Freight Performance Measure (FPM) implementation in the United States for possible implementation within the Texas Department of Transportation's (TxDOT) division of transportation, planning, and programming. A review of current FPM work revealed several state and federal initiatives and led the team to work closely with American Transportation Research Institute (ATRI) staff in determining Texas-based FPM data for the state. The study sponsored a FPM workshop, in which federal initiatives were presented together with study findings on current performance-based work. This report presents a review of current FPM work, details the ATRI-FHWA study currently underway, presents some early ATRI data on Texas highways, explores the potential interface between FPM corridor work and the Texas Transportation Institute (TTI) urban performance indices, and finally, makes recommendations for TxDOT on future FPM research and implementation in the state.

17. Key Words	18. Distribution Statement
Freight Performance Measures, Interstate Corridors, Truck Tracking, FPM	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.

19. Security Classif. (of report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	86	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Robert Harrison
Mike Schofield
Lisa Loftus-Otway
Dan Middleton
Jason West

CTR Technical Report:	0-5410-1
Report Date:	August 2006
Project:	0-5410
Project Title:	Developing Freight Highway Corridor Performance Measure Strategies in Texas
Sponsoring Agency:	Texas Department of Transportation
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

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Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

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Robert Harrison, Research Supervisor

Acknowledgments

The authors wish to acknowledge the involvement and direction of the Texas Department of Transportation (TxDOT) project monitoring committee—specifically, Project Director Greg Malatek, PE (SAT); Project Coordinator Lonnie Gregorcyk, PE (YKM); and Project Monitoring Committee Members: Chad Bohne, Clayton Ripps, Gary Humes , Mark Wooldridge, and Sergio Garcia.

Special thanks are also owed to Crystal Jones, Office of Freight Management and Operations, Federal Highway Administration, for her guidance and assistance throughout the project and for her participation at the project workshop held in Austin, Texas in May 2006. Special thanks are also owed to Jeffrey Short, American Transportation Research Institute, for his assistance and participation throughout the project, the case study trip to Austin, Texas in April 2006, and at the Workshop held in Austin, Texas in May 2006. Finally, thanks are owed to Mark Milam (CTR), who arranged and organized the Workshop in May 2006 and provided administrative assistance in the production of this document.

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1. Introduction

1.1 Overview

> "If you don't measure results, you can't tell success from failure. If you can't see failure, you can't correct it."
> —Kassoff

Since 1990, the U.S. economy has moved from a regional focus—exemplified through the implementation of the North American Free Trade Agreement (NAFTA)—to a global one, particularly linked to the various economies of Asia and the European Union. Global and regional trade has grown commensurately, and the transportation corridors along which the trade moves—termed *supply chains* by the logistics industry—have experienced substantial growth in demand.

Transportation corridors of this type are multi-modal in nature and can involve several modes transferring the product from origin to destination. Highways, the modal subject of this scoping study, play a major role in moving trade efficiently in the U.S.; however, increased congestion and related time delays have become critical problems as a result of high demand and a lack of funding to build new highway capacity. Congestion problems first manifested themselves at the urban level and research attention focused on auto congestion through the 1990s, and the impacts of congestion on freight traffic were not studied as intensively.

During the same time period, transportation planning and policy began to focus on performance measurements to help implement projects that systematically improved traffic congestion, safety, or pollution. This effort began with the Government Performance and Results Act (GPRA) in 1993 (Public Law 103-62 103rd Congress), which addressed concerns with government accountability (OMB, 2000). While the move towards performance-based planning is still in its infancy, the completion of major initiatives recently at the federal level, as well as at many of the state departments of transportation (DOTs), seems to indicate that the U.S. is at a turning point. Many planning agencies throughout the country are at a stage between completing the planning required to create appropriate goals and performance measures and executing them.

During this push towards performance measurement, the focus has been primarily on passenger vehicles, which ultimately left freight, especially motor carriers, out of performance evaluations. It is therefore unsurprising that a number of trucking industry managers conclude that highway congestion, and more importantly trip *reliability*, are now among the primary concerns of the motor carrier industry. Transportation agencies are looking at toll roads as a solution to the congestion problems that many metropolitan areas are facing, but until recently, few agencies have attempted to quantify in any way the specific needs of the freight industry in this regard. In the past several years, a handful of DOTs, most notably Minnesota and New Jersey, have begun looking into some broad indicators of a more efficient freight system, but as of 2006, the work done by the DOTs has not expanded to the point of defining national standards or measures. What was lacking was a clear understanding of what constitutes freight performance on highway corridors, how performance should be measured and how the information derived from the measures can be used to improve state and federal highway networks.

The Federal Highway Administration (FHWA) has addressed the lack of national consensus on Freight Performance Measures (FPM) with a 2003 project conducted by the American Transportation Research Institute (ATRI). This research evaluated various technologies for tracking motor carrier movements in the U.S. for possible use in developing freight performance measures and finally settled on using data from global positioning system (GPS) units already installed in many motor carrier fleets. This research—termed FHWA/ATRI in this report—is multi-phased. It began with a "proof of concept," moved into evaluating five interstate systems over a one-year period and is currently exploring FPM use with seven state DOTs and is monitoring thirty-five interstate highways. The past 3 years have shown that this data has a wide range of uses applicable to identifying the failures, successes, and needs of the highway system as it relates to freight movement. The review of freight performance measures, undertaken in this study, is therefore both timely and relevant for TxDOT as it plans for increased international trade destined for Texas or traveling on the various interstate corridors to regional destinations

1.2 The Motor Carrier Industry and Its Concerns

An understanding of the motor carrier industry defines why FPM strategies are needed and also outlines the benefits of developing FPMs. The motor carrier industry can be divided into two distinct categories, which often share similar goals: private carriers and for-hire carriers. Private carriers transport goods for their own companies, while for-hire carriers are contracted by a shipping company to deliver their cargo. Given the intense competitiveness that has always been present in the shipping industry and the increase in technologies of the past several decades, for-hire motor carriers have become increasingly dependent on information technologies of various types to remain competitive and provide quality service for their customers. Private carriers have never been far behind the initiatives of for-hire carriers and have also implemented technologies of many kinds to record the performance of their own fleets and drivers and to ensure cargo security.

The common link between for-hire and private motor carriers is the need for both to adhere to strict schedules. For private carriers, as the popularity of just-in-time operations has increased, shipping has become more directly linked to demand in the short-term. For a just-in-time business plan to work, with its low stock of inventory at places of sales or manufacturing, shipping must be timely and efficient, and even more importantly, reliable. For-hire carriers inherently have the same challenges because their clients have the same challenges as private carriers. Often with hired shipping companies, deliveries that are not on time can result in penalties for late delivery. Conversely, early delivery can lead to logistical problems for shipping managers at truck terminals or distribution centers. Clearly, reliability of expected travel time is a chief concern in all segments of the shipping industry.

1.2.1 Motor Carrier Issues

Although some technological solutions to industry challenges have been developed, a number of operational issues persist. While it is not always the responsibility of the state to resolve these issues for the motor carriers, several of the issues relate to problems outside of the carriers' control but within the areas of influence of the state or federal departments of transportation. Often these issues could be dealt with by integrating freight performance measures into the planning process, either in the short-term (dynamic FPM use) or long-term (static FPM use).

Several studies over the past few years have examined the major issues in the motor carrier industry. The Federal Highway Administration supported a study involving a direct survey of fourteen experts in the motor carrier industry who were asked to rank the top fourteen operational issues in order of importance. The fourteen experts surveyed included regional carriers, as well as long-haul carriers, and the experts represented drayage, truckload, and less-than-truckload carriers (ICF Consulting, 2003). This diversification was meant to give a fairly balanced view of issues within the motor carrier industry, although there was no indication of any weighting of the experts within their carrier niches to properly represent the industry as a whole. Table 1.1 lists the top issues, according to these industry experts, and their average ranks. Many of the issues, particularly those near the top of the list, are beyond the control of the departments of transportation: rising insurance costs, fuel price volatility, and emissions standards. However, some of the concerns are within the realm of issues that can be addressed by performance-based planning with the use of some as yet undetermined data collection methods: urban congestion/travel time reliability and delay at port terminals. The focus of the Chapter 2 section "Effective FPMs for Describing Freight Mobility" will be identifying FPMs that may be able to address these issues.

Table 1.1: Top Issues of the Motor Carrier Industry

Issue	Average Rank
Rising Insurance Costs	2.6
Hours of service rules changes	3.6
Fuel price volatility	5.4
Urban Congestion/Travel Time Reliability	5.6
New emissions and fuel standards	6.1
Driver waiting and loading times	6.9
Security concerns	7.3
Truck size and weight limits	8.7
Driver turnover	8.7
Ergonomics regulation	9.4
Safety concerns and NAFTA	10.1
Shortage of vehicle mechanics	10.1
Introduction of truck toll roads	10.7
Delays at port terminals	12.4

Source: ICF, 2003

Another study addressing the issues of the motor carrier industry was an American Transportation Research Institute (ATRI) study completed by partnering with the Center for Transportation Studies at the University of Minnesota (Donath and Murray, 2005). This study identified a list of nine operating issues for motor carriers. In many ways, these nine issues align with those identified by ICF Consulting in Table 1.1, although slightly more aggregated. The nine major issues presented in this study are

1. Highway taxes and user fees
2. Driver shortages
3. Insurance costs
4. Fuel price volatility
5. Hours of service
6. Technology utilization issues
7. Congestion and capacity
8. Shipper-carrier relationships
9. Maintaining a safe industry.

Two areas continually mentioned in studies of motor carrier issues are congestion/capacity and the related issue of travel reliability. These are also issues where initiatives by state departments of transportation could assist the motor carrier industry, and some would argue, assist the movement of all traffic by so doing. In the two studies cited earlier, congestion was listed in the top nine major issues of one and received a rank of 5.6 in the other, showing the perceived importance of this problem. This perception and the accompanying attitudes of motor carrier industry workers towards congestion have been researched (Golob and Regan, 1999), along with the possible implementation of technologies that could help alleviate this problem.

The Golob and Regan survey of 1,998 of 1,200 private and for-hire carriers in California was one of the first of its kind, determining the industry's views on congestion, its effects on their schedules, and possible solutions. The study found that the increase in fuel and insurance costs, reliability and scheduling problems, and crashes caused by congestion are believed by more than half of the survey participants to have a larger impact than traffic delays alone. About 88 percent of those surveyed said that drivers sometimes (or often) work in congested areas at present, while 85 percent stated that they believe congestion will get worse in the future. Congestion makes just-in-time delivery rather difficult, with 62 percent of drivers saying they sometimes fail to meet schedules due to congestion. In addition, the mental health of drivers is also a concern, with many drivers reporting a serious effect on their patience and morale

Given the existing challenges within the trucking industry, two questions remain. The first: what FPMs can be implemented that can help resolve the issues of congestion and reliability? This highly debatable question should be answered using basic performance-based planning steps that are agreed upon by the most planning agencies. This question will be answered in the section "Effective FPMs for Describing Freight Mobility" in Chapter 2. Secondly, what technologies need to be implemented to collect data for these FPMs and how could this data best be used for both the short and long-term? Much of this data is already being collected by carriers on the road, but the sharing of data is not being undertaken in a way that allows it to be implemented into any performance measure. This data collection concern and other issues will be discussed later in Chapter 2, in the section "Data Collection Issues for Effective FPMs."

1.3 Study Objectives

The primary purpose of this scoping report is to summarize the status of freight performance measures used in DOTs nationally and suggest a set of universal freight performance measures, applicable regardless of which technologies are available to the user. The secondary purpose is to look into various applications, both real-time and long-term planning, for the truck GPS data that is currently being collected as part of the FHWA/ATRI study.

Several objectives were necessary to accomplish this goal. First, a general literature review was conducted. The literature review had four categories: urban corridors, the FHWA/ATRI work, the growth of intensive truck traffic generators, and a general open-ended literature review of examples of freight performance models being used to enhance planning. Next, the research team met on several occasions with the FHWA/ATRI research team to discuss their work on freight performance measures and to help TxDOT be in a position to participate in the ongoing FHWA/ATRI work. The research team also interacted with Tim Lomax and David Schrank at the Texas Transportation Institute to determine their views on the FHWA/ATRI approach, compared to their work on urban congestion measurement and how intercity and urban corridor FPMs might be linked. The research team also investigated technologies that can be used to collect data relevant to freight performance measurement. Project workshops were held on May 11, 2006 to present work performed to that date and to introduce the FHWA/ATRI team to TxDOT personnel. The final study tasks considered how both urban and intercity corridors are being analyzed in the United States and how this will impact Texas freight performance measurement strategies.

This study is organized into seven sections. Chapter 1 introduces the study objectives. Chapter 2 is a literature review, providing an overview of performance measures in the transportation planning and freight performance context. Chapter 3 documents the FHWA/ATRI work and reviews and summarizes national progress in this area. Chapter 4 identifies technologies that can be used for collecting data needed for freight performance modeling. Chapter 5 catalogues work undertaken by the Center for Transportation Research and the American Transportation Research Institute (ATRI) on further analysis of ATRI freight performance data to prepare for the TxDOT workshop. Chapter 6 analyzes the possibilities for linking ATRI's intercity performance metrics into the urban corridor freight performance currently used. Chapter 7 summarizes the work and presents key conclusions.

2. Performance Measures in Transportation Planning

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and the GPRA of 1993 both put an emphasis on performance, so performance measures have been near the forefront of U.S. transportation policy. The most commonly accepted factors encouraging this trend in planning include:

- A reduction in available resources as compared to current transportation needs,
- A need to get user support for infrastructure investments, facilitated by the easily communicable results of performance measures,
- More timely response to transportation needs, and
- The desire of the customer to increase the accountability of decision makers involved in public spending. (TRB Proceedings 26)

Most advantages of performance measures are founded in the desire of the users and owners of our transportation system to get more value from the dollars they spend. This goal is possible through the pro-active approach of defining performance measures that have a reliable data source and are understandable to an audience broader than transportation planners alone. Finally, the performance measure information should be formatted to guide, through changes in the measures, decision making in the planning process. Performance measures are not a trend that will soon become obsolete in transportation planning but will be a permanent and integrated part of the planning process used by transportation agencies.

2.1 Types of Performance Measures

The performance measures used by an agency should be established with a precise understanding of its products. The hierarchy in transportation planning is goals, described by objectives and quantified with performance measures. Figure 2.1 shows the elements of a performance-based planning process, particularly how changing goals, creating performance measures, collecting data, and evaluating can be a cyclical process. This vision can include the transportation or community goals of the agency, but it can also simply address information needs of the decision makers. Orienting around the product or goal can help ensure that a change in the value of a performance measure is adequately gauging progress or digressing towards the completion of an objective. Without a clear definition of objectives, the measurement of performance indicators can lead to ambiguous planning and less than the best use of resources.

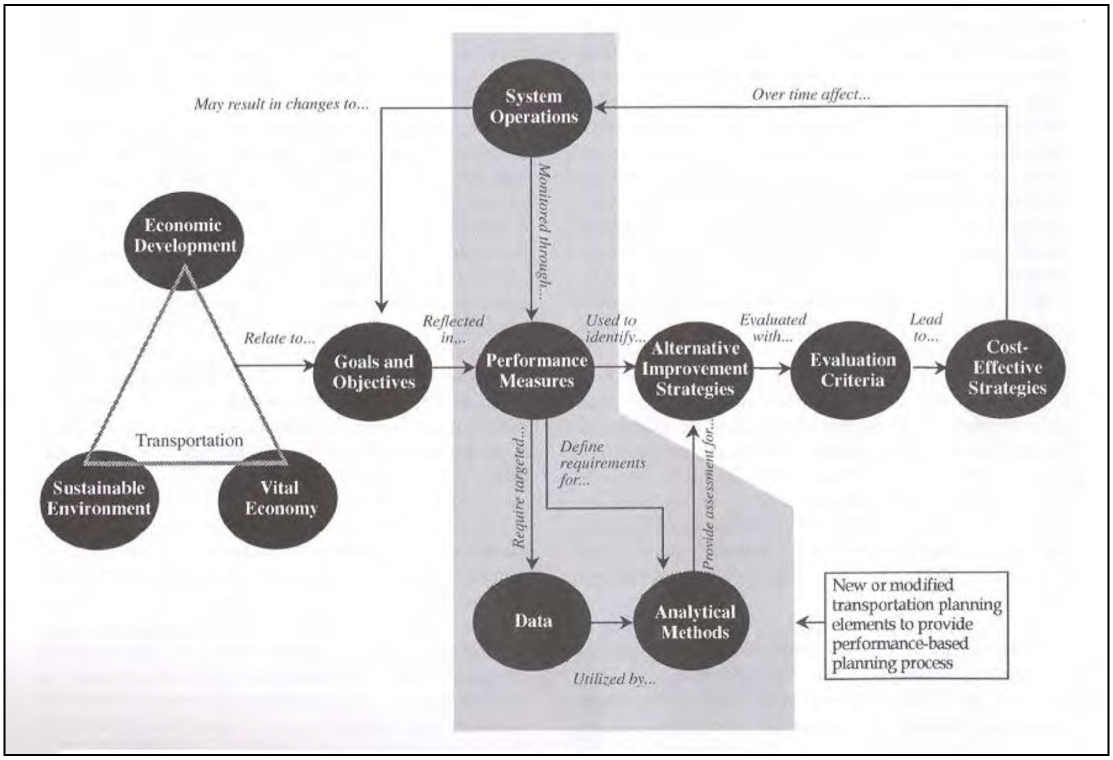

Figure 2.1: Elements of Performance-Based Planning
Source: Cambridge Systematics, Inc., 2000

A given set of objectives can lead to a variety of informational needs. This information can be provided by performance measures classified in three categories:

1. Input: performance measures that relate to the amount of resources spent on a specific problem or in a specific region (e.g., dollars spent to alleviate environmental transportation problems);
2. Output: performance measures that relate to physical progress being made in a specific area (e.g., TxDOT's Strategic Plan 2007-2011 performance measure for number of two-lane highways with improved shoulders); and
3. Outcome: performance measures focusing on improvement over time (e.g., TxDOT's Strategic Plan 2007-2011 performance outcome projection for percent of construction projects completed under budget and on time).

It is important that decision makers take all three performance measure types into account to get an accurate picture of resources expended, the immediate result of those expenditures, and the eventual result of the expenditures. By utilizing these viewpoints, policy makers can evaluate the success of their policies and modify them appropriately. Good performance-based planning leads to performance measures that are dynamic—constantly changing and improving to meet public needs.

2.2 Important Features for Performance-Based Planning

While performance-based planning systems have been summarized in a variety of ways over the years, this has not always led to improved understanding or application of performance measures. Many agencies have used outlines that have remained static; typically they contain a minimum of five broad steps: setting the goals of the agency, refining goals into specific objectives, specifying measurable indicators, data collection and evaluation, and the use of the results. Figure 2.2 shows the iterative nature of these five steps and their applications—in this case—in improving intelligent transportation systems (ITS).

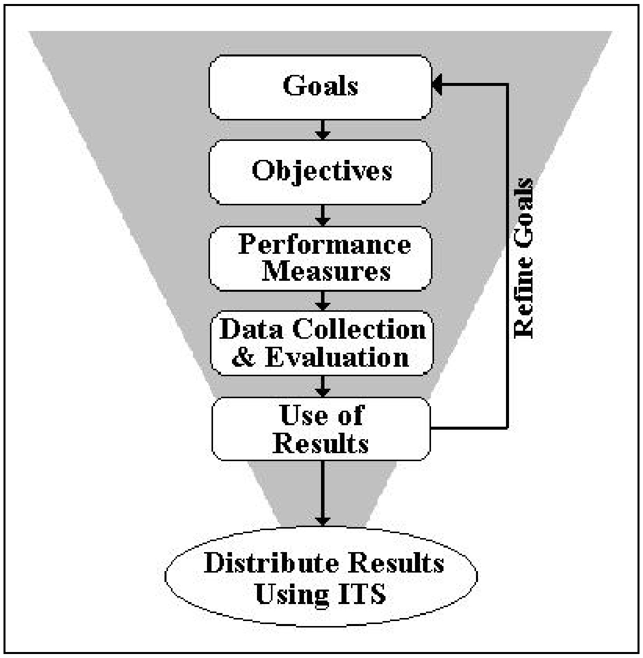

Figure 2.2: Five Steps of Performance-Based Planning

2.2.2 Goals

The goals or policy directions of a transportation planning agency are generally quite broad. They are also dynamic, and in a properly working system, they are based on results from the last period of performance-based planning. For example, the Minnesota Department of Transportation (MnDOT) has developed the *Minnesota Statewide Freight Plan* and has six goals to improve regulatory transactions, statewide infrastructure, international freight infrastructure, and operational performance and safety (MNDOT, May 2005). The plan is also moving to integrate the freight plan with the general transportation plan and to build stakeholder partnerships. These six goals form a framework and vision for the agency to provide direction but are broad enough to remain flexible and allow change each year as necessary.

2.2.3 Objectives

The objectives or strategies of an agency reflect the goals and are the measurable components in performance-evaluated planning. This approach makes sure that the objectives, if achieved, will actually have an impact on the overarching goals. Six strategies have been identified for the first goal to improve statewide freight infrastructure in the MnDOT freight plan. One example of a strategy is to "Improve the efficiency, condition, and capacity of intermodal terminals (Minnesota Department of Transportation, 8-3)."

2.2.4 Performance Measures

As objectives or strategies are quantifiable details of the overall goals, performance measures can focus on specifying a measurable indicator of how well the objective is being completed and provide information for the decision-making process. Tracking performance measures that are not linked to a specific objective uses resources that could be better spent elsewhere. Causality should also exist between a performance measure and matters that planners can affect. If a problem cannot be solved by tracking performance, then using performance-based planning is not appropriate. An example of a performance measure to improve statewide infrastructure in the *Minnesota Statewide Freight Plan* is the "percent of intermodal facilities whose infrastructure condition is adequate (Minnesota Department of Transportation, 7-7)."

2.2.5 Data Collection and Evaluation

A simple but important question to ask before creating a performance measure is "What are the data requirements and is data collection feasible?" If collecting the data is not feasible or the required analysis is not possible, little will be gained from following through with the performance measure. Performance should also be evaluated regularly when data is readily available. The closer decision makers get to real-time data collection and evaluation, the more quickly and efficiently they can respond to problems and ameliorate their effects.

2.2.6 Use of Results

This step in the performance-based planning process is the most open ended because it is entirely up to the decision makers to decide how the results of the evaluation are used. It is also probably the most critical step, because failing to take full advantage of the results wastes both time and money. It is important, therefore, that decision makers attempt to take advantage of every facet of utility.

One utility is information feedback to decision makers who are creating goals and defining objectives. Through this regular feedback, the full potential of performance-based planning can be realized. In theory, feedback leads to increasingly small changes and an eventual meeting of goals. An equally important audience for receiving performance information is the user of the system. This interaction not only helps increase accountability for decision makers, but also assists the user in making more informed travel decisions.

2.3 Advantages of Performance-Based Planning

Given the public sector's reasons for making a gradual shift to a performance-based planning system, there are implied advantages to using performance measures. These typically fall into three categories: communication with the public, accountability on the part of the planners to make effective decisions, and an overall improvement in operations.

2.3.1 Communication

As a direct result of making objectives that are explicit and quantifiable, with a focus on progress, communications between decision makers and the general public may occur. A good performance measure will be easily understandable and measurable, creating new clarity that eases communication among members of the transportation planning forum: agencies, planners, and the public.

2.3.2 Accountability

Setting specific performance-related goals allows agencies to focus their resources on specific problem areas, increasing efficiency, and improving the connection between the objectives of decision makers and the objectives of the users of the infrastructure. Overall, this "reflects a shift in agency thinking away from simply output (e.g., "tons of salt applied") to outcome (e.g., "reduction in ice-related fatalities") (Cambridge, 2000). This focus on objectivity creates a method to track whether both long-term and short-term goals are being met and whether resources are being allocated appropriately, resulting in an overall increase in agency accountability.

2.3.3 Operational Improvement

Performance-based planning establishes clear goals that are maintained over time. The elapsed time allows planners to gain a better understanding of how the decisions they make impact transportation in their areas of responsibility and encourages an agency to make systematic improvements.

2.4 Characteristics of Effective FPMs for Describing Freight Mobility

The main challenges of performance measures of all types are fairly similar and certainly applicable to performance measures designed specifically for freight movement. One basic concern is developing a performance measure that is simple enough that data collection is possible and represents traffic conditions. Furthermore, the measure is beneficial when it can identify changes in the transportation system and provide an understanding of how adjustments in transportation management or the implementation of transportation projects affect the objective area. Both issues are integral because without data collection, the performance measure is not measurable and, without proper representation, the performance measure will not be useful to planners and transportation stakeholders. If planners do not utilize both criteria when creating a performance measure they run the risk of developing freight performance measures that do not drive ongoing performance evaluation. General transportation performance measures often used to evaluate intermodal freight performance can be found in Table 2.1.

Table 2.1: General Transportation Performance Measures Often Used to Evaluate Intermodal Freight Performance

Indicators	Measures	Strengths/Weaknesses
Travel time	• Average travel time in peak period • Crossing time at Borders, weigh stations, toll plazas • Hours of delay per 1,000 vehicle mile	• Data often not readily available • Focuses on one point of network • Delay associated with commuter traffic
Reliability	• Hours of incident based delay • Percent of on-time arrivals • Ratio or variance to average minute per trip in peak periods in metro areas	• Need to disaggregate recurrent versus incident-based congestion • "On-time" is a subjective measure and a moving target. Data held privately and difficult to access • Reflects seasonal fluctuations as well as unexpected incident delay
Cost Measures	• Cost of highway freight per ton-mile • Fuel consumption per ton mile • Maintenance cost of connector links	• Can be skewed by other exogenous factors • Good reflection of highway condition • Maintenance spending can be negative and positive—does not indicate an improvement in highway condition—could be wasteful spending
Safety/Damage	• Accident rates • Fatality rates • Insurance cost	• Data is limited on costs associated with these measures • Can reflect other conditions e.g., driver experience and theft levels
Highway Condition	• Lane-miles of high level highway requiring rehabilitation • NHS intermodal connectors condition • % of roads/bridges with surface/condition classified as good • Number of at-grade railroad crossings • Overpasses with vertical clearance restrictions • Weight restricted bridges • Intersections with inadequate turning radii	• Quality measures that don't accurately reflect effect with any specificity for freight and applies to all users • These are impedances to freight but may be on segments not used by the freight industry
Economic Impact	• Contribution of investment to GDP • Net present value of improvements/ Benefit-cost ratio of highway improvements	• Difficult to separate passenger travel effects • Most of these benefits are associated with passenger travel and do not disaggregate the freight element.
Industry Productivity	• Average length of haul/average load/ percent of VMT empty • Annual miles per truck	• All measure output per unit of input and capture productivity of industry but not the relationship to highway system

Source USDOT, 2000

Developing performance measures that affect the private sector is even more problematic because the state must understand the basic business models of the motor carriers to understand the changes that may occur in freight mobility. At the FHWA National Freight Transportation Workshop in 2000, a representative of Oregon DOT briefly discussed the challenges inherent in developing performance measures.

> "Using performance measures to identify transportation improvements can be an example of a public sector activity in which private sector participants lose interest over time. Performance measures that sound good conceptually often are problematic to implement because the data needed for measures are not available, are available but difficult or expensive to obtain, or are not reported regularly enough to be useful. Muddling through efforts to develop and implement performance measures can be intensely arduous for public sector staff, and even more so for private sector representatives trying to help through service on advisory committee. Keeping the effort simple is excellent advice but not always easy to follow. ODOT continues to seek the proper balance between meaningful and easy to measure performance standards and criteria." (Streff, 2000)

One of the main purposes of developing freight performance measures is the basic assumption that giving users of the highway system relevant information will alter their route decisions, because choosing the faster route can make the difference between late deliveries and on-time deliveries for truckers. This is especially the case for intercity trips. In a 2003 study by the National Cooperative Highway Research Program, it was found that motor carriers performing intercity deliveries are more prone to change itineraries if they are made aware of traffic conditions, such as increased travel times or decreased operating speeds (Shaw, 2003). This supports the idea that congestion, especially on intercity corridors such as Interstate 10 and Interstate 35, could be impacted by the distribution of information detailing the travel times on multiple corridors at various times of the day. Among the issues still to be resolved are how this data could be collected and how it can be distributed to users, freight or otherwise, of the highway network.

2.5 Determining Effective Freight Performance Measures

> "The data-collection needs for implementing a comprehensive set of overall ITS performance measures far exceeds the data-collection capabilities within the state. As a result, the latest efforts focus on measures that are easily achievable and measurable." (Colorado DOT, 2005)

When determining appropriate performance measures of any kind, in this case FPMs, it is important to ask the questions that have been stressed throughout this report: Is it possible to collect data to support the performance measure? Would the results of such an action be useful to users or policy makers? Is there a goal or level of successful performance? If the answer to any of these questions is negative, the measure in question will most likely not be a successful FPM.

This report will address possible FPMs of any type that would benefit users or planners, but will go into the most detail about measures that are possible using data that could be shared from vehicles in motor carrier fleets serving as data sources. Information from trucks can come in the form of GPS data or transponder readings at a weigh station. GPS data only includes the position of each unit and its coordinates, but it could be immensely useful to planners in maintaining a variety of measures.

As obvious as it may seem, an FPM is simply a performance measure related to freight and should therefore follow all the basic guidelines when creating performance measures. For this study, these basic guidelines were followed for determining appropriate FPMs for emerging users:

- Capable of being measured—If data is not currently collected, it should be at least feasible to accomplish,
- Capable of capturing deficiencies—A proper FPM should not measure conditions without a purpose but should rather diagnose a problem for a specific policy or planning objective,
- Capable of measurement over time—Measures should be standardized enough to allow continued collection and time-series comparisons,
- Capable of being forecast—The most useful FPMs will allow planners to solve problems before they occur if current data can be forecast to show future deficiencies,
- And easily understood by both decision makers—If the FPMs are to make any difference, they must be understandable to decision makers.

2.6 Relating Five Steps of Performance-Based Planning to FPMs

As determined in the section "Important Features for Performance-Based Planning" in Chapter 2, there are five major steps to the performance-based planning process: setting goals, determining objectives, specifying performance measures and indicators, collecting data, and the use of the results, which can take a variety of forms. These steps are completely applicable to freight performance measure planning at any level, particularly for emerging users of FPMs.

The goals of any freight performance plan should be generally broad yet applicable to most planning agencies. Assuming performance measures have been used in the past, these goals will be an improvement over the previous year's goals, based on the measured findings. In a constantly changing environment such as highway conditions and use, this becomes an iterative process. For freight, two goals are fairly straightforward: ensure that the transportation system allows freight carriers to transport goods efficiently and reduce the negative impacts associated with freight movement. These goals form a framework and vision for the agency with which to determine the planned objectives. These objectives, for many agencies, form five PM categories comprising mobility, reliability, economic issues, safety and environmental impact, and infrastructure concerns.

Table 2.2 defines twelve freight performance measures/indicators that could be of importance to emerging FPM users. Each is then elaborated upon in terms of reasoning and data needs, but specific targets are not set as these are largely dependent on the current state of performance and the priorities of the planners for the planning area—in this case, Texas.

Table 2.2 Suggested Freight Performance Measures for an Emerging User

Category	Potential Indicators
Mobility	Intercity Travel Times Average Speed on Freeways, by Route and Time of Day Major City Congestion Levels Compared to Other Metro Areas Volume/Capacity of All Vehicles on Freeway Segments
Reliability	Deviation of Travel Times or Speeds from the Average Frequency of Nonrecurring Delays Portion of On-Time Motor Carrier Arrivals
Economic	State Transportation Investment vs. Gross State Product
Safety/Environment	Emissions Freight Related Crash Rates
Infrastructure	Pavement and Bridge Quality Average Delay Time at Border Crossings

2.6.1 Mobility

Mobility is described primarily by travel time. Intercity travel time is a critical measure and a dominant issue among those shippers concerned with reliability (ICF Consulting, 2003). Because the majority of the mileage traveled by trucks is intercity, a state would want to attempt to improve intercity travel time between its own cities. Intercity trip segments often lack the data sources, such as loop detectors, needed to determine travel times. GPS time and position data, if made available to planners, could be used to find the average travel time from city to city at any time of day or day of week. This data might not be limited to transportation planning objectives in the future but could be used to create a real-time series of data that could be used to improve transportation operations. The section on the FHWA/ATRI work will mention the difficulties that might limit real-time applications with GPS data. Performance targets could be set in a variety of ways, but one reasonable method would be describing travel times as a percentage of those experienced under free flow conditions.

Average speeds of motor carriers on freeway segments of any size would also be a significant measure to describe the overall freight mobility performance of the highway system. This measure could be calculated using GPS data from units already installed in many trucking fleets, with a preference in the future for the data to be capable of providing real-time information that can be passed onto system users. A performance target speed could be used for each corridor, but a simpler and more meaningful method is to use a percentage of free-flow speeds, generally the speed limit.

A comparison of congestion levels compared to other metropolitan areas, most likely as a percentile, is an achievable FPM, using data already being collected as of 2006. The *Urban Road Congestion* report by the Texas Transportation Institute (TTI) includes annual congestion indexes for more than 70 major metropolitan areas. Although the reporting tends to lag 2 to 3 years behind measurement, it is an important indicator of a city's performance, and a large carrier survey found that 82 percent of respondents believe congestion is at least a somewhat serious problem for their business (Golob and Regan, 1998). TTI is undertaking other work on urban congestion and Chapter Six provides details of these activities and how urban and corridor FPMs might be combined.

The ratio of highway volume compared to capacity is also a well-accepted means of measuring the performance of a highway for all users. This method and data already exists and does not need to be updated for freight-specific travel. Assuming there are no truck-only lanes, the volume occupying the freeway during peak hours is just as important to trucks as it is to passenger vehicles.

2.6.2 Reliability

Despite the importance of reliability to the trucking industry, accepted standards for measuring reliability do not exist. The deviation of truck travel times on highway segments from the average is an important indicator of reliability. No additional data would need to be collected beyond that used for intercity travel time or average motor carrier speeds, only additional manipulation of the data. A possible performance target for this indicator would be the travel time that corresponds to one standard deviation above the average travel time over a segment. The goal would be to improve the Travel Time Reliability (TTR) value over time. A similar reliability standard would be an Average Speed Reliability (ASR) over any chosen highway segments. While indices like the Texas Transportation Institute's (TTI) Buffer Index can be useful, it could also be argued that standard deviation is a more common measure of reliability.

For example, the following would calculate the Average Speed Reliability on a designated segment of highway over an entire week-long period:

$$ASR_n = \sqrt{\frac{\sum_{i=1}^{N}(Speed_i - AvgSpeed)^2}{N-1}}$$

Where N = # of trucks passing through highway segment n in a given study time
$Speed_i$ = the speed of truck i as it travels the segment
AvgSpeed = the average of all $Speed_i$ terms

Nonrecurring delays, like those taking place outside of normal peak congestion times, have remained quite difficult to track. The inability to decipher nonrecurring delays in intercity trip segments remains a concern because such delays are among the leading reasons for highway unreliability. With GPS data being collected from motor carrier fleets, however, this condition could change. Real-time data collection and analyzing could make time-varying congestion on highway segments well defined. With these peaks defined, any additional spikes could be recorded as a nonrecurring delay, which most commonly occurs during crashes and extreme weather conditions.

The portion of motor carrier movements arriving on time is the most accurate indicator of the reliability of a highway system, although it cannot be determined from any easily obtainable data. While many shippers track this information themselves to minimize penalty fees, retrieving this sensitive information would be difficult. Similar to the Golob and Regan survey of 1998 stating that drivers sometimes (62 percent) and/or often/very often (27 percent) fail to meet schedules, a survey could be administrated on an annual basis, determining whether any efforts made to improve reliability have been effective.

2.6.3 Economic Measures

A common concern for the freight sector is whether the capital investment in transportation, particularly highways, is keeping up with the economic growth of the state or nation. This is a fair concern, considering that much of that growth may be linked to freight shipment. Although there may be a time lag, transportation spending information should be readily available. As a comparison with a state's domestic product, this could be a simple but useful tool for relating the growth of both. It may be valuable for a planning agency to create a FPM that decision makers can use to justify continued or targeted investment in transportation funding to ensure their economies continue to grow. This measure could be as simple as a ratio of transportation funding growth over total economic growth.

2.6.4 Safety and Environmental Impact Measures

Freight-related crashes are a concern for both social and economic reasons. By measuring this data, DOTs can minimize the impact of trucks on the highway, possibly by their separation from other vehicles. Tracking crashes over specific highway segments requires collation of crash data already collected by state departments of public safety or commercial vehicle enforcement, but aggregated spatially, to provide planners time-series data regarding the occurrence of crashes. The most effective performance target would likely be either incidents or fatalities per million ton-miles, possibly both.

Air quality issues are important to the public, especially in areas where these issues have been ignored in the past. Federal regulations also require attention to air quality conformity and emissions. Creating an FPM and setting performance targets, such as tons of pollutants per ton-mile or vehicle-mile, for example can show that improvements to infrastructure (such as improving bottleneck areas and the use of ITS and other congestion mitigation measures) would help to lower truck emissions. Using accurate counts of truck traffic and speeds from truck GPS data, models such as MOBILE from the Environmental Protection Agency can be employed by DOTs on highway segments to determine problem areas. Similarly intermodal bottleneck data collected by MPOs, planning agencies, cities, and counties could also be used to provide performance measures at intermodal facilities on the network.

2.6.5 Infrastructure Measures

Pavement and bridge quality data throughout many states largely exists in various forms such as the Pavement Management System and Bridge Management System. Setting a goal for these quality levels can be extremely important for freight movement on an operational level and is also linked to fleet maintenance costs and safety. Performance targets for this measure would be most reasonable as an A to F level of service.

Although delay at border crossings could be viewed as simply a component of total delay, it is important enough to be measured separately, especially in border states such as Texas. The increase in Mexico-U.S. trade traffic after the signing of NAFTA created delays at the border ports of entry that continue to impact shipping efficiencies (U.S. Customs Service, 2004).

Traditional modeling techniques do not capture this information, nor do traditional delay-reducing techniques affect this portion of delay. The obvious performance target would be average delay per truck at each border crossing, but such data does not currently exist. New forms of data collection, perhaps GPS positioning data, would need to be implemented to determine the time between a truck's entering the queue and crossing the border.

After determining the performance measures needed to meet the objectives, it is important to establish the current and future needs to meet those goals. The New Jersey Institute of Technology (NJIT), for example, has put these needs into a simple equation, which is important to remember during all stages of performance-based planning to keep focused on stated goals (NJIT, Page III-27, July 2003):

Needs = Goals - Performance

2.7 Data Collection Issues for Effective Freight Performance Measures

In many cases, when freight is involved, data is collected, used in the short-term, and discarded. Often data is used by the motor carrier for competitive decisions and is not provided to public transportation agencies. The data being collected daily by motor carriers, comprising GPS time and position data, could solve many of the data collection problems faced by agencies thinking of implementing FPMs.

An issue currently making this data difficult to obtain is both political and a natural result of motor carrier competition. Many of the larger carriers, which have several units from their fleet operating on a single corridor at any given time, can accomplish a limited perspective of the goals outlined in this report without state support. These carriers might gain a significant amount of useful information on route congestion from the data of other carriers by providing their own data, but the smaller carriers will inevitably gain more. This could result in the larger carriers giving up a significant market advantage, which would be unappealing to them. Therefore, any attempt by the state to provide information to all motor carriers could lessen the amount of control the larger carriers have over travel information and alter the nature of competition between the carriers. However, this information is beneficial to all users of the interstate system, both freight carriers and passenger vehicles, and increases in overall efficiency could provide some incentive for larger carriers to share their information. As one study stated, shippers in the Minnesota area have urged MnDOT to share performance data with them, believing that "good information flow will build support for transportation investment and will help balance the interests of shippers and the traveling public" (Larson and Berndt, 1999). Information sharing is also cyclical and symbiotic; information that motor carriers might provide is helpful to agencies, the shippers themselves, and the general public.

Assuming this information is acquired, the next step is implementation. Implementation helps the users on the highway system, both passenger and commercial, and assists planners in making more informed decisions. Chapter 3 discusses the state of practice in freight performance measures in the U.S. and highlights states that have made inroads into developing FPMs. Chapter 4 provides a review of technologies that are being used to provide data for FPM implementation.

3. State of Practice for Freight Performance in the United States

Freight performance measures in the U.S. are currently at a very early stage in their development. Some states have made a push to look into FPMs or to begin some data collection to assess what would be required for an integrated ITS-PM system. However, most states have not yet utilized their performance measures across modes. The general consensus is that the implementation of a comprehensive set of FPMs requires far more data-collection capability than most states currently possess.

This places a majority of DOTs in the early planning stage of FPM development. States that have made a notable start towards FPM integration include California (Barber and Grobar, 2001; Jones, 1995), Colorado (Colorado DOT, 2005), Florida (Florida DOT, 1998), and Oregon (Monsere, et al., 2005; Reiff and Gregor, 2005). Individual studies have ranged from port performance in California to more ITS-related highway studies in Colorado. However, these states have mostly focused on broad goals and objectives, rarely getting to the specific details of performance measures and addressing the data-collection requirements of these FPMs. Freight planning has been conducted in many regions of Texas, but freight performance measures have not been developed.

A review of freight planning in Texas and general transportation performance measures is now introduced to compare with the freight performance measures used in other states. Two states that have addressed these issues stand out and seem to be on the cusp of implementing some of these measures in a meaningful way: Minnesota and New Jersey. These state programs are also discussed.

3.1 Texas

Freight planning in Texas has been conducted at both the state and regional level. TxDOT has funneled most initiatives for freight through its Transportation Planning and Programming Division with a focus on improving rail systems. The agency has identified rail relocation as a major component of its strategic plan (TxDOT Strategic Plan for 2007-2011, 2006). The strategic plan also describes how projects that have restricted trucks from using the inside lane have improved safety conditions. The Transportation Commission in conjunction with the Legislative Budget Board has also identified and developed performance measures to use when describing performance to the state legislature in the bi-annual strategic plans. The measures define all modes of transportation without segmenting between freight vehicles and passenger vehicles. Some of those measures included:

- Number of statewide centerline miles of two-lane highways equal to or greater than 24 feet pavement width as a percent of total two-lane centerline miles
- Percentage of additional travel time due to peak period congestion
- Number of fatalities per 100,000,000 vehicle miles in the state, and
- Number of oversize/overweight permits issued annually.

On a local level, the metropolitan planning organizations have been instrumental for freight planning efforts. Two MPOs that have made significant efforts are the Houston-

Galveston Area Council (HGAC) and the North Central Texas Council of Governments (NCTOG). In 2000, HGAC sponsored a *Strategic Freight Corridor and Needs Assessment Study* (Houston-Galveston Area Council, 2000). The study included an inventory of intermodal freight facilities and access needs and recommendations. NCTOG has a goods movement group that coordinates freight meeting activity for the region through the Intermodal Freight and Safety Subcommittee of the Regional Transportation Council. A freight bottleneck study has also been conducted by the group, which included an emphasis on truck movement through the region (NCTOG, 2004). Although the subcommittee has not developed a formal freight performance measures plan, several freight indicators are being used to describe the trends in truck traffic and to identify freight bottlenecks. These freight performance measures include:

- Percent of trucks in total traffic counts.
- Travel time contours in the vicinity of sites that are intensive truck trip generators.
- Trucks per day.

3.2 Minnesota

Minnesota is one of the more notable states looking seriously into using freight-specific performance measures in the near future. This is reflected both in the amount of information that MnDOT has published in recent years, and also because of the level of detail offered in their plans from the very start. This is quite rare at most early stages of performance-based planning, but also necessary to get a quick and effective start.

A 1999 study by the Minnesota Freight Advisory Committee (MFAC) recommended a series of freight-specific performance measures that were much more specific than typical performance measures introduced for development (Larson and Berndt, 1999). Rather than the typical "decrease highway crashes" recommendation for a safety measure, the MFAC recommended both "Dollar cost of crashes" and "Crash rate per mile traveled by freight mode." The study broke down possible measures into four categories, the typical transportation, economics, and safety, as well as "Bottlenecks and Impediments," measuring the impediments to freight traffic. This level of specificity is important to give planning agencies direction on their choice of measures and their relative importance. In addition, proposed measures were broken down into two primary segments, those that could be measured with available data and those that would require further development. This type of segmentation, while often ignored, makes the job of the DOT much simpler by pinpointing the areas where data is currently available but unused, and provides a stronger case than simply stating all possible performance measures.

MnDOT also used the 1999 study as a basis for creating five priority outcomes related to freight needs. These "Family of Measures" led the way towards performance-based planning in 2003 following previously formulated strategic directions:

1. Time/Directness—A predictable travel time for length of trip is maintained so that customer expectations are met.
2. Safety—Incidents and crash rates are minimized to MnDOT's current and potential ability to influence infrastructure and driver behavior.
3. Condition of Infrastructure—An infrastructure that meets customer expectations is maintained.

4. Access/Basic Levels of Service—Services are provided to meet personal travel and shipping needs.
5. Socioeconomics—Balance investments with an evaluation of community values and social impacts.

The 2005 Minnesota Statewide Freight Plan further specified the FPMs, building on data and experience from the first few years of implementation (MnDOT, 2005). This document classifies all of the performance measures as:

- Developmental measures—a commitment would need to be made to set any targets,
- Emerging measures—data is available, but no targets have been set, or
- Mature measures—data is available and targets have been set.

In the case of the "mature measures," the targets are specified (e.g., "Percent of rail track-miles with track speeds greater than 25 mph"), and in the case of the measures with data collected, an example is shown in Figure 3.1.

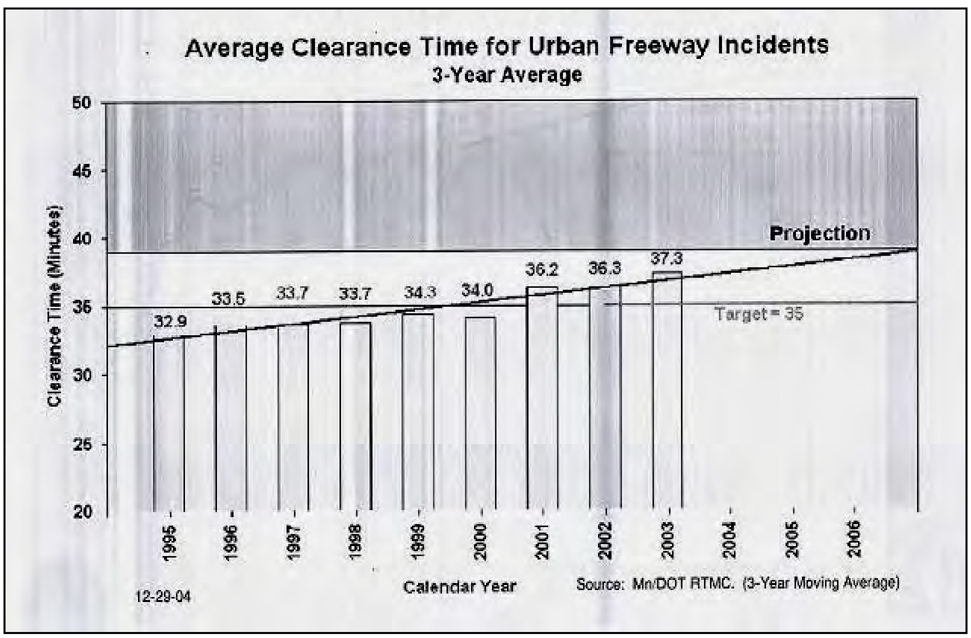

Figure 3.1: Average Clearance Time for Urban Freeway Incident
Source: MnDOT 2005

Figure 3.1 shows the time taken to clear the freeway after incidents in urban Minnesota areas. This is based on a three-year moving average to help reduce outliers—possibly false indicators—which is a good approach for any performance measure. Data between 1995 and 2003 determined the projection, and a performance target clearance time of 35 minutes was instituted by the agency. Data beyond 2003, the start year of performance-based planning in Minnesota, could show the effectiveness of MnDOT policies related to clearance time as the target measure is implemented.

3.3 New Jersey

The North Jersey Transportation Planning Authority, Inc, which serves as a metropolitan planning organization for thirteen counties in northern New Jersey, is one of the FPM implementation leaders for the state. NJTPA sponsored a 2003 study by NJIT that was distinguishable from the other states due to the level of detail with which they have extended their FPMs into the future, an aspect largely ignored by most agencies when developing the early stages of performance-based planning (Fallat et. al, 2003). Planning performance measures over a long time period and not just using a single flat goal can make the measures more dynamic and effective over time.

In developing FPMs, NJIT sets its first goal as identifying current indicators of performance in the state and identifying data collection that is currently undertaken but unused; a common occurrence in planning at all levels. Figure 3.2 shows the current truck traffic on New Jersey highways.

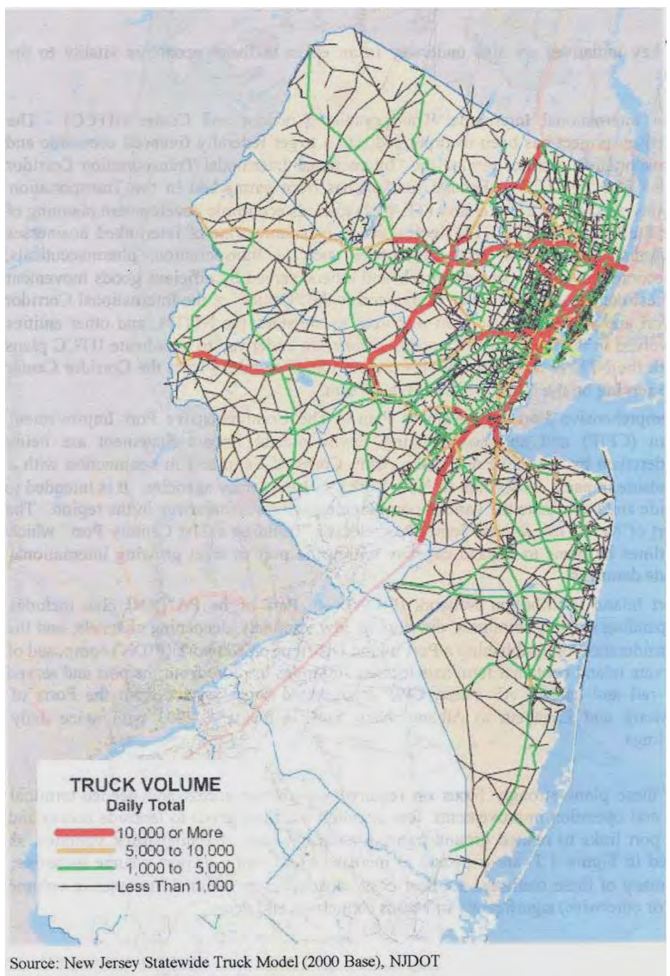

Figure 3.2: New Jersey Truck Volumes

This data is fairly simple to collect but is largely ignored or calculated as a predetermined percentage of passenger volume, which is an inaccurate estimate for many corridors. The importance of this data collection is important to performance-based planning, as it can lead to the determination of traffic density. This system of estimating truck volume by demand modeling is far better than the alternative of not using any data at all, but a preferable system would be collecting data on truck traffic directly, without the effort of manual counts. The possibility of acquiring this data through the sharing of information already on-board most motor carrier fleets will be discussed further in Chapter 4.

NJIT's current standard of organizing performance measures lists its suggested FPMs in eight broad categories and from there determines (i) potential indicators in each category, (ii) data and data collection needs for the indicators, (iii) current and future levels of the indicator where data is available, (iv) performance goals, and (v) current and future needs to meet performance goals. This approach is a straightforward method of arranging FPM programs and was taken into account in Section 2.5 and Section 2.6, where FPM measures that could be implemented by a transportation planning organization were introduced.

The NJIT recommended indicators fall mostly into five categories, similar in some areas to the current and recommended FPMs of Minnesota:

1. Average Travel Time Measures—Congestion delay
2. Private Sector Cost Measures—Fuel Costs Per Mile, Insurance Costs
3. Public Impact Measures—Freight-related Crash Rates, Emissions
4. Economic Impact Measures—Value of Transportation Goods, Impact of Transportation Investments to Regional Economy
5. Transportation Industry Productivity Measures—Vehicle Miles Traveled, System Performance (by survey), Average Haul Length

At the state level, the New Jersey Department of Transportation (NJDOT) does have a Comprehensive Statewide Freight Plan with Phase 1 completed in 2004 (Parsons Brinckerhoff-QD, Inc, 2004). The plan identified the development of performance measures as a key issue. In developing the plan, NJDOT interacted with the MPOs in New Jersey including the NJTPA and will use the MPO's tools in its own efforts. The NJTPA Strategy Evaluation Tool and Travel Demand Model are available to NJDOT for freight mobility evaluation and to determine truck trips.

3.4 Oregon

Other states do not have a comprehensive freight performance measurement program like Minnesota and New Jersey but do have measures for freight traffic within general plans. The Oregon Department of Transportation (ODOT) has defined policy areas that are important for state transportation planning. Performance measures have been selected to evaluate progress in these twelve categories: economic vitality, balanced transportation system, sustainability, adaptability, mobility, quality of life, environmental justice, system preservation, land use compatibility, affordability, and safety and security (Reiff and Gregor, October 2005). Reiff and Gregor developed six measures because of a lack of performance indicators for some of the categories mentioned earlier. One of the six measures addressed economic vitality, which was not adequately defined with prior performance measures. The new measure developed for evaluating changes in economic vitality was freight delay costs and can be considered as a freight performance measure.

The freight delay cost performance measure requires that truck trips be tracked throughout the network and that both nonrecurring delay and recurring truck delay be modeled or directly measured for the truck trips. The methodology used is from the Texas Transportation Institute Urban Mobility Report, with slight variations in establishing the quantity of truck vehicle miles traveled. The Oregon II statewide model is then used to determine freight delay cost. The Oregon II statewide model can determine hourly delay costs for different trucks and different commodities and includes vehicle operating costs, driver costs, and average costs of commodity delay (Reiff and Gregor, October 2005). ODOT staff notes that the freight delay cost measure has limited value in describing economic vitality, but it can be applied to a variety of transportation planning jurisdictions including small MPOs, the Portland Metro model, and statewide models. The advantage to using a performance measure like freight delay cost is that it is easily understood by the public, versus measures that are communicated as ratios or percentages.

3.5 California

The Division of Transportation System Information within the California Department of Transportation (CalTrans) has led the state's effort in transportation performance measures. The overall goals for this effort were to establish measures that would both monitor the state transportation system and help transportation planners make informed decisions (CalTrans, October 2000). Furthermore, the initiative was also intended to lead to an ongoing performance measurement within CalTrans. Within these efforts, performance measures for freight systems have been defined for all freight modes and the following objectives: safety, reliability, mobility/accessibility, equity, economic well-being, and environmental quality (Booz-Allen & Hamilton Inc., June 1999). Most of the measures are compared against established baselines. The measures for each policy objective are shown in Table 3.1.

Table 3.1: California Performance Measures

Policy Objective	Performance Measure
Safety	# of crashes x 1,000,000 / truck vehicle miles traveled
Reliability	Standard Deviation of Travel Time
Mobility	Travel time, Delay
Accessibility	Access to intermodal facilities
Equity	Regional share of mobility benefits
Economic Well Being	Final demand
Environmental Quality	Emission quantities in lbs per year

Source: California Department of Transportation, 2000

These measures are used for either monitoring the transportation system or forecasting transportation performance or usage. Those measures that are used for both monitoring and forecasting include safety, mobility, accessibility, and environmental quality. The reliability objective is for monitoring only, while economic well-being measures are only used in forecasting.

The policy objectives of safety, mobility, accessibility, reliability, and environmental quality have been evaluated for strengths, weaknesses, and future direction needed to further promote usefulness of measures addressing these areas. When considering truck traffic only, data sources to describe safety are available through the California Highway Patrol. The data needed to define mobility, accessibility, and reliability is available from loop detector data, which is primarily limited to urban areas. Collecting the same information in rural regions is not as prominent and has led to researching other methods, which includes the FHWA/ATRI studies using GPS, together with pilot testing of both dedicated short range communications and cellular phones to track vehicles when not on roadways with loop detectors.

3.6 National Freight Performance Measures—FHWA/ATRI Truck GPS Data Use

The Federal Highway Administration (FHWA), through its Office of Freight Management, entered into partnership in 2003 with the American Transportation Research Institute (ATRI) to develop methods to measure the performance of freight corridors, with the goal of facilitating more efficient goods movement. Measuring freight performance will represent an improvement in local, state, and federal agency planning in their ability to identify and deal with freight-specific problems.

The ATRI study, "Developing Real-Time Performance Measures in Freight Significant Corridors" (ATRI, 2003) did not ignore other modes but focused on the trucking industry, because it represents an 87 percent modal share in the U.S. (ATA, 2004).

3.6.1 FHWA/ATRI Phase I

Phase 1 of the FHWA/ATRI partnership began in 2002 and had three goals. The first step in the work plan for the partners was to identify freight significant corridors in the country and to review technologies that could be used to collect truck location data. Then, the selected technology was tested for performance. An ATRI partnership with a technology vendor who provided GPS reports from trucks in major cities was ultimately recommended as the preferred method. Data from this approach was then compared to the corridors identified in the Cambridge Systematics report, *Evaluation of Performance Measurement: Travel Times in Freight-Significant Corridors Phase 1 Final Report,* to yield five corridors for further study. Carriers operating on these corridors and willing to share their data through the vendor (after aggregation) were identified as data providers for this phase. Using the truck position reports, five complete interstate systems were evaluated (as shown in Figure 3.3). Two of these systems are freight-intensive segments critical to Texas, namely:

- Houston–Dallas via I-45
- Houston–San Antonio via I-10

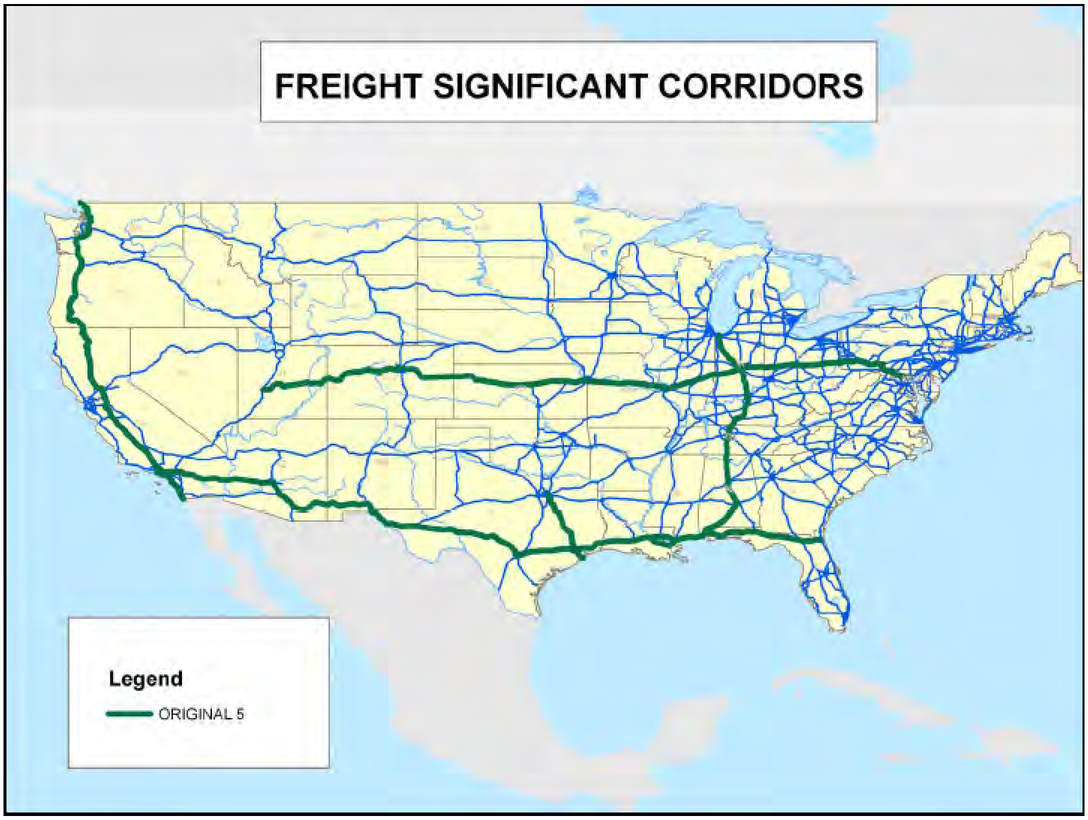

Figure 3.3: Five Interstate Corridors Selected for Analysis
Source: ATRI/FHWA, 2003

The next portion of Phase I work investigated technologies that could be used to collect position information on trucks. A variety of data collection technologies were considered for the study, some of which are discussed Chapter 4 of this report. Satellite tracking is accomplished through the onboard GPS units, described in detail previously, and offered the best service in rural areas. Terrestrial tracking involves the use of cellular technology, providing good metropolitan coverage, but inadequate intercity coverage limits its use on certain corridors. Hybrid tracking systems incorporate pieces from each of the previous two technologies, most likely using terrestrial tracking for urban areas and satellite tracking for intercity regions. A fourth technology is on-board computer tracking, which has no connectivity to outside systems, making it difficult to process the data and relate it to specific highway segments. Information collected from fixed site systems used to read transponders is mostly related to electronic toll collection systems such as EZ pass (a toll tag RFID method) or weigh stations supporting electronic clearance systems. While this is an inexpensive alternative because the infrastructure is already available, at the moment it is limited in coverage. Of the five alternatives, satellite tracking was chosen as the most suitable positioning alternative for use in intercity data collection.

There are two data collection capabilities available within the technology categories: Data Burst Technology and Continuous Flow Technology. Data Burst Technology allows for "near real-time" vehicle movement information through the sending of data packets and regular time intervals. Continuous Flow Technology constantly transfers data to the system in actual real-time. One of the limitations of the currently available GPS truck satellite tracking systems is that a 60-minute delay can occur between readings on each truck because of carrier policy, making any real-time FPMs collection difficult or impossible to institute. This problem will be discussed further in Section 4.3, "Data Collection Technologies." The overall goal of Phase I was to develop a methodology for measuring travel speeds over a corridor. FHWA and ATRI were then ready to start Phase II of the partnership as the freight significant corridors had been selected and an initial methodology for measuring travel time developed.

3.6.2 FHWA/ATRI Phase II

The emphasis for Phase II of the FHWA and ATRI partnership was to refine data collection processes and analysis methods while collecting GPS data. Three months of data were collected in 2005 for the five corridors selected in Phase I, and this data consists of a timestamp and position of properly equipped trucks along selected corridors. Each timestamp is associated with a specific truck but that vehicle is given an alphanumeric identification to eliminate tracing timestamps to a carrier, while still allowing for the truck to be tracked along a corridor. Other collected information included the date, time, and latitude/longitude. A sample of this data is shown in Table 3.2.

Table 3.2: Sample of ATRI Data Generated from GPS

ID	Time	Latitude	Longitude
POLXGB	4/2/2004 04:06:00	48.1022	-122.185
LLBLPXE	4/2/2004 04:10:00	42.6044	-123.384
OP11RE	4/7/2004 11:40:00	48.4175	-122.333
BXLESXB	4/8/2004 20:41:00	34.2925	-118.469
X10BLPE	4/8/2004 20:41:00	35.2992	-119.259

Source: Short, 2006

By determining the location of these selected trucks on about an hourly basis, ATRI staff was able to develop average travel rates (in minutes per mile), an average congestion metric (Travel Time Index [TTID]), and a reliability metric (Buffer Index [BI]). The TTID is a measure of mobility calculated by dividing the observed travel time by a free-flow travel time (assumed 60 mph for freeways). The BI is a measure of travel time reliability and variability that measures how much extra time one should allow to account for variations in the system while still arriving on time 95 percent of the time. In the project workshop conducted for the Texas Department of Transportation, ATRI staff indicated that the equation used for the BI is a ratio of the difference between the 95th percentile travel rate and the average travel rate over the average travel rate as shown with this equation:

$$BufferIndex, BI = \frac{\left(\begin{matrix} 95thPercentile\ Travel\ Rate \\ \text{(minutes per mile)} \end{matrix} - \begin{matrix} AverageTravelRate \\ \text{(minutes per mile)} \end{matrix}\right)}{\begin{matrix} AverageTravelRate \\ \text{(minutes per mile)} \end{matrix}} * 100\%$$

Table 3.3 shows the results of the TTID and BI along with state travel rates for Interstate 5. These measures allowed FHWA and ATRI to test the concepts that were developed in Phase I and conduct a proof of concept demonstration for the freight performance measures. After successfully completing Phase I and II of the partnership, Phase III was initiated to expand the size of the data collection efforts. This stage of the work was also designed to allow FHWA and ATRI to begin working more closely with the state transportation agencies on how the freight performance measures could be used effectively in transportation planning and to help validate findings made during the course of Phase III.

Table 3.3: Travel Time in Freight Significant Corridors: I-5 by State, July 2005

State	State Travel Rate	State Travel Time Index	State Buffer Index
Washington	50.30	1.20	17.98
Oregon	49.44	1.23	8.60
California	49.51	1.23	29.43

Source: Short, 2006

3.6.3 FHWA/ATRI Phase III

Phase III of the partnership was an expansion of work conducted during Phase II. The corridors analyzed were the five selected during Phase I, but all of 2005 was included in the study, as opposed to Phase II, in which only 3 months of data were included. This phase of the study also began to consider border crossing analysis in July 2005 for United States/Canada border crossings. In addition, this phase began by testing whether the FPM data were accurately describing irregular conditions on the corridors related to weather incidents or geometric/geographic constraints. Figures 3.4 and 3.5 portray two cases in which the GPS data detected poor corridor performance, and the researchers from ATRI and FHWA were interested in determining the cause of these anomalies. If a valid reason could be established, then the potential use of the GPS data to quantify corridor freight performance would be established.

Figure 3.4 shows FPM data for Interstate 70 as it traverses through Denver, Colorado. The diagram clearly indicates that the speeds observed west of Denver are slower than the speeds east of the city. FHWA and ATRI were able to verify that field conditions at this point on the corridor were similar to those found in the FPM data. The mountainous terrain west of Denver has a significant impact on average speeds, especially for trucks, while land east of the metropolitan area is prairie lands and average speeds are higher. The second case, shown in Figure 3.5, highlights traffic conditions in New Orleans, Louisiana during Hurricane Katrina. The results from FHWA and ATRI analysis indicated that commercial vehicles were not operating on I-10, which was expected due to the weather conditions and closure of Lake Pontchartrain Bridge.

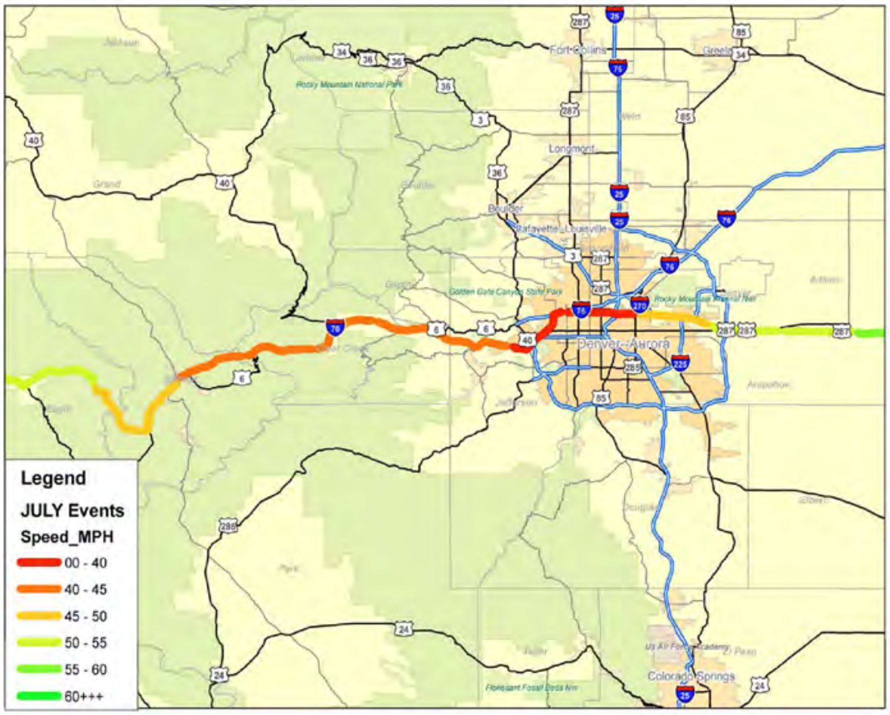

Figure 3.4: Interstate 70—Denver, Colorado
Source: Short, 2006

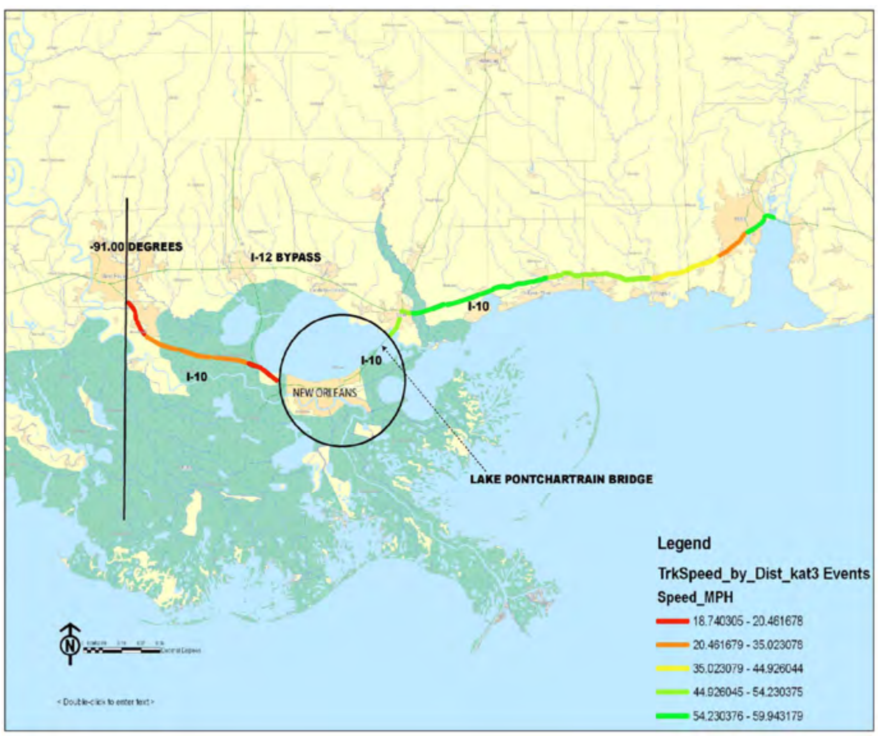

Figure 3.5: Interstate 10—New Orleans, Louisiana, September 1-7, 2005
Source: Short, 2006

During the course of this scoping study, ATRI staff visited the Center for Transportation Research (CTR) to discuss these cases and to collaborate on validating data collected from those corridors located in Texas. The results from that analysis are given in Chapter 5. Future steps for the FHWA/ATRI partnership include expanding to 25 the number of interstates being analyzed and interacting with state transportation agencies to determine how the FMP data can be used in freight planning. The following seven states have been selected for case studies:

- Colorado
- Florida
- Indiana
- Maryland
- Missouri
- Texas, and
- Washington.

FHWA and ATRI have continued the partnership by meeting with planning staff from these states to continue exploring the application of FPM for freight transportation planning.

4. Status of Freight Performance Measure Data Collection Technologies

4.1 FPM Implementation and ITS

GPS data taken from motor carrier vehicles for freight performance measures has two separate uses: (a) policy-changing potential that the information has in the hands of planners, and (b) real-time transmission of highway data to users. The latter could come in the form of transmission via signing or some form of wireless technology (cell phone/internet/on-board computer) which then permits more informed driver decision-making. It could also be communicated to traffic management centers for real-time reporting of highway incidents involving nonrecurring delays. The basis of much of this data use is the assumption that the speed of the truck sample providing GPS data represents not just trucks, but also passenger vehicles. This is based on the assumption that a truck traveling below the speed limit is not doing it by choice, but due to weather conditions, traffic conditions, crashes, or congestion—precisely the same conditions that would lower the speed of a passenger vehicle. This chapter discusses technologies that could allow for a feedback-based FPM implementation.

4.2 Data Collection Technologies

4.2.1 Dedicated Short Range Communications

Dedicated Short Range Communications (DSRC) is a system that relies on transponders and automated vehicle identification readers (AVI) to detect the presence of a vehicle. Transponder technology has grown in popularity with law enforcement agencies, shippers, and carriers as an option to improve the performance, safety, and security of moving freight by commercial vehicles. State initiatives to participate in the national Commercial Vehicle Information Systems and Networks (CVISN) program have increased the benefits of participating in programs to bypass weigh inspection facilities. These efforts rely on identification of commercial vehicles equipped with transponders capable of transmitting a signal that is read as the identification for a truck. After the signal is captured by the roadside antenna, automated vehicle identification (AVI) readers located at the weigh station collect information on the identification of the truck and the time at the facility. The truck identification is checked against agency databases for compliance with safety and registration regulations. If the truck also complies with weight restrictions, it is allowed to bypass the facility. The detection of the same truck at a downstream weigh station on the same roadway allows travel times and average speeds to be measured. The potential for using the time stamps of commercial vehicles that arrived at a weigh station will be more promising if the enrollment of motor carriers into electronic clearance programs is successful.

Studies have shown that the technology can be used to provide data for freight performance measures like travel time on a corridor. McCormack and Hallenbeck noted that freight traffic volume, average mean speed, 85^{th} percentile speed, and 95^{th} percentile speed can be derived from AVI reader data (McCormack and Hallenbeck, 2005**).** Wright and Dahlgren have described the use of vehicles with transponders providing travel times with three cases:

TransGuide in San Antonio, TransStar Traffic Monitoring System in Houston, and the New York/New Jersey TRANSCOM System for Managing Incidents and Traffic. The data collection in San Antonio has 53 detection sites while TranStar in Houston has 290 reader sites. The New York/New Jersey TRANSCOM System for Managing Incidents and Traffic costs $1.4 million. Its system includes 22 readers on 22 miles of road. The spacing of the readers varies from .5 to 2 miles apart. They have also identified speed and travel time performance measures that can be described from data collected by AVI readers.

Other research efforts have studied how accurately the technology depicts travel conditions and has investigated using the technology to describe freight performance. The AVI system in San Antonio was studied in 2001 to compare the performance of the technology, versus the more traditional loop detector for detecting incidents in the freeway network. A loop detector is a circuit placed in cuts within the pavement connected to an electrical device that sends a current through the wires (Hass et al, 2001). Whenever a vehicle travels over the detector, the inductance of the loop changes, and the vehicle's presence is noted. Two inductive loops placed in series can be used to measure vehicle length and speed. Determining the performance of AVI against the loop detector system helps gauge whether AVI is sufficient as a traffic probe and establish initially whether the technology is appropriate for travel time estimation.

The study used a 10-mile segment of I-35 to compare loop detectors versus AVI for incident detection (Hass et al, 2001). The data collected from the two technologies was also used to measure speeds over a segment that was further divided into links. The AVI technology measures space mean speed. The space mean speed is the ratio of distance between detection points and time needed to travel that distance. In contrast, since loop detectors measure instantaneous speed, the information gathered from loop detectors can be used to calculate time mean speed at a specific point in the corridor. The time mean speed describes the arithmetic average for vehicles detected by the loop detector over a given time interval. The space mean speed for the loop detector data can be found indirectly, and thus, the AVI and loop detector speed measurements can technically be compared. The results for one link during the morning peak period on September 25, 2000 showed that the differences in speed estimation for the two technologies could vary from 0 to 10 mph (5 percent to 10 percent). Space mean speeds were 60 mph to 70 mph depending on technology when data was collected. During times of congestion, the results were more varied and less accurate than found on September 25th. The final conclusion was that the vehicular probes with the AVI technology do provide good space mean speed estimates.

A team of researchers from the Washington State Transportation Center examined the factors that affect whether trucks equipped with transponders can provide reliable information for freight performance measures (Hallenbeck et al., 2003). Trucks equipped with transponders in Washington participate in bypass programs at weigh stations. Readers in the weigh-in-motion program are located primarily along I-5 and a single reader on I-90. The readers used for the border clearance program are fixed at the Port of Tacoma, the Port of Seattle, and at the Blaine Customs station at the Washington/British Columbia border. Trucks participating in these programs can serve as vehicle probes used to calculate travel times. An important component of using transponders to determine travel times on a corridor are truck volumes and the location of AVI readers. Although the study concluded that using trucks equipped with transponders can technically produce travel times and is promising, the data have limitations and lack completeness in describing travel conditions on a corridor when the truck volume density of AVI readers is inadequate.

Truck volumes along a corridor affect the usefulness of information provided from transponder reads at weigh-in-motion stations. AVI readers in Washington are located in Ridgefield, Fort Lewis, and Stanwood-Bryant along I-5. The average number of tag reads at the sites changes noticeably between sites and from weekdays to weekends, as shown in Table 4.1. Depending on whether the location is between a major origin and destination pair or more of an isolated location has an impact on the number of reads at the site. The Ridgefield location is between Vancouver, Washington and the Seattle area and has a high number of reads compared to the Stanwood site, which is north of the Seattle area and has lower truck volumes at this point on the corridor. Truck volumes affect the time that passes between reads. The strategy for identifying bad data works well when truck density is high but is not as effective when a high percentage of time gaps between truck transponders exceed 15 minutes. A comparison of the two segments on I-5 show that the time gap between the Ridgefield to Fort Lewis gap is 5 minutes or less 90 percent of the time, while the time gap for the segment between Fort Lewis and Stanwood Bryant is 5 minutes or less only 35 percent of the time (Hallenbeck et al., 2003). The segment between Ridgefield and Fort Lewis provides more reliable data than the Fort Lewis to Stanwood Bryant segment.

Table 4.1: Comparison of Tag Reads at Weigh-In-Motion Inspection Stations

AVI reader location	Average Weekday Reads	Average Weekend Reads
Ridgefield	1258	468
Fort Lewis	1007	366
Stanwood Bryant	381	124

Source: Hallenbeck et. al., 2003 Figure 22

The distance between AVI readers, together with truck volumes are primary factors in measuring travel times correctly. Transponders used in the electronic clearance program are currently used for regulation purposes in Washington, which makes the data collection method less expensive. The problem with the method is that the AVI readers are located in the network at locations used for enforcement and are not designed for the purpose of collecting travel time information. This distance provides many opportunities for trucks to exit the interstate and make stops. A transponder-equipped truck that is identified by consecutive readers but stopped during the trip cannot be included in travel time analysis. The study identifies unusable readings by comparing travel times to vehicles that were both identified at the first reader within 5 minutes from each other.

Performance measuring was impacted by the small number of reader locations, the long distance between readers, and the location of those readers on mostly major rural routes where truck volumes are lower. Most of the fixed readers are on interstate corridors and limit the information available from state highways. The use of portable readers would allow the state department of transportation to collect data on corridors that are not equipped with fixed readers at automated commercial vehicle enforcement sites. A proposal has been introduced to improve data collection by using semi-portable readers that would cover undetected areas or shorten the distance between existing readers. A full scale test of semi-portable readers was to be conducted in the Vancouver area during August 2004 (Hallenbeck et al., 2003). Table 4.2 provides a breakdown of associated costs.

Table 4.2: DSRC Costs for Measuring Travel Time/Average Speed

	Transponders	
	Item	**Cost**
Equipment	Reader	$1,500
	Solar Panel	$500
Installation	No Structure	$5,000
	Structure	Additional $1,500
Communication	Month of Cellular Phone	$50
Analysis	Simple	$1,000
	Complex analysis for Vancouver	$25,000
Total		**$21,050 up to $35,550**

Based on the findings in this study, the effectiveness of using RFID to determine travel time is dependent on the distance between readers and truck volumes. Travel time derived from transponder readings can be affected by low roadside reader density and truck volumes producing biased data but the technology is still promising for Washington due to the low costs of transponders and the increase in trucks using transponders.

There are challenges to using transponders to provide information for quantifying freight travel times in Texas. First, no program exists that encourages carriers to participate in electronic clearance programs. Weigh stations in Texas do not have electronic screening or bypass possibilities, which are important for generating user interest. Second, if AVI readers were to be located at current inspection stations in Texas, the distance between readers, especially in rural areas throughout Texas, would be even farther than the average 100 miles for the Washington sites. The third issue is whether the truck volumes will be sufficiently high along intercity Texas corridors locations to use the information compiled with the transponders and AVI readers. This concern will exist in rural areas regardless of the technology. Although these issues need to be addressed, freight performance measures of average travel time or *expected* travel time for lower traffic volumes can still be calculated for a segment to evaluate the performance of a corridor.

4.2.2 Cellular phones

Cellular phones have also been listed as a potential technology to determine travel times on a corridor, but pilot tests have not investigated how cell phones can be used to describe freight movement only. Yim and Cayford did an initial study on the use of cell phones to derive performance measures (2001). The researchers used a dataset from US Wireless, which is a company producing cellular phone tracking technology. The dataset held 44 hours of collected vehicle location data. With the 44 hours of data, travel time for 107.4 kilometers (66.74 miles) of roadway was known. In the same study, global positioning (GPS) devices produced 58.6 kilometers (36.41 miles) of travel time information with only 3.5 hours of tracking data. Clearly, GPS performed better than the cellular technology in this study, but the GPS capabilities in cell phones have improved since this 2001 study.

At the time of Yim and Cayford's study, cell phones came in two varieties: network and handset. The network-based cell phones do not have GPS capabilities and use network triangulation to determine the location of the cell phone. The handset-based cell phones have GPS and the ability to figure the cell phone's location without assistance. The ability for a handset cell phone to discern its location improved as the standard GPS technology advanced. Now, assisted GPS (A-GPS) uses a central server to request the location of a GPS device, and the GPS uses satellites to determine its latitude and longitude (Globis Data). Then, the reading is sent back to the server and is corrected using algorithms to adjust for errors. The adjusted latitude and longitude is then established. A Canadian-based study evaluated cellular phones with A-GPS, similar to technology tested as a stand-alone device in truck cabs by the American Transportation Research Institute (ATRI) and the Federal Highway Administration (FHWA).

Transport Canada is the only transportation agency that has published findings on the use of cell phones equipped with A-GPS[1] and they developed a complete testing program (Kirk et al., 2005). As a cell phone was located, the speed was measured and contributed to determining an average speed on the corridor. Maps labeling the road segments green, yellow, and red were then used to display the speed of vehicles moving through the corridor. The accuracy of these findings was checked against the observations of drivers reporting speeds in a road segment at a given time (observed or instantaneous traffic speed) and the odometer and time reports from drivers used to provide calculated speed (average speed). The results of the Transport Canada study on highway traffic were somewhat disappointing, as shown in Table 4.3. For example, map results showed green conditions on seventeen segments, but only eight out of the seventeen segments were calculated to be green.

Table 4.3: Initial Cell Phone Tests on Canadian Highways

Color	Map Result	Observed	Calculated
Green	17	17	8
Yellow		0	7
Red		0	2
Green		9	4
Yellow	15	5	9
Red		1	2
Green		1	0
Yellow		1	1
Red	2	0	1

Source: Kirk et al., 2005

[1] Although a few states like Maryland and Virginia have demonstrated an interest in using vehicles with operators using cell phones as traffic probes.

Changes to the algorithms did demonstrate promising results as represented by a new test on Highway 417 in west Ottawa, Ontario (Kirk et al., 2005). In this test, segments were green on the map, and 42 segments where observed (instantaneous speed) to be the same. Thirty-four vehicles had an average speed at the posted speed. By making changes to the algorithms used to determine speeds on a segment, it is possible to improve the measurement of the data collection. Now that cell phones can be equipped with (A-GPS) in Canada, the technology is similar to the stand-alone GPS devices onboard in the FHWA/ATRI study discussed in Section 3.4.

The key elements to using quality data from cell phones to describe traffic conditions are (a) cell phone usage in the area, and (b) the number of cell phones detected for a road segment and time period—in other words, the sample size. The technology used to identify vehicle location and figure travel time also has an impact on the quality of cell phone-generated travel information. In 2003, AT&T Wireless and Cingular Wireless were using network based technology, while Nextel, Sprint PCS, T-Mobile, and Verizon all used handset location technologies. Nextel, Sprint PCS, and Verizon handsets were also equipped with A-GPS (Yim, 2003). Although carriers and state DOTs like the Missouri Department of Transportation are using network triangulation methods, A-GPS seems to be the better method for figuring travel times. The Canada study also indicated that algorithms used to process data might have to be refined, even with technology such as A-GPS to get accurate readings. Last, a downfall to the use of cell phones is that tests have not been conducted on using the technology to describe truck movements only, as has been accomplished with DSRC or GPS.

4.2.3 Global Positioning System

Global Positioning System (GPS) technology is widely used by state transportation departments for a variety of planning applications. A study sponsored by the FHWA indicated that 32 states have used GPS for planning purposes (Turner-Fairbank Highway Research Center, 2000). Some of those uses included highway inventories, land use planning, and the combination of Geographical Information Systems (GIS) and GPS for mapping and survey purposes. GPS has also been used to provide traveler information and has been tested for determining travel times on corridors. The Arizona DOT used GPS in ITS pilot tests with its Advanced Traveler Information Systems (ATIS), and Kansas and Louisiana DOTs have considered using GPS to establish travel times for corridor and congestion management systems.

GPS can be used to determine travel times and speeds on a corridor. Since 2000, pilot tests have studied how vehicles equipped with GPS devices can serve as traffic probes. The travel time study conducted by ATRI and FHWA used GPS devices, and pilot tests examining how GPS can be used to understand the performance of a corridor have been performed through the California PATH research program and the Washington State Transportation Center.

The first GPS pilot test was conducted by Cayford and Yim in 2001 and also included the analysis of cellular phone tracking, which will be discussed in the following section. The study was conducted on the eastbound and westbound lanes of I-580 in the California Bay Area (Cayford and Yim, 2001). The devices used in the tests included the standard GPS unit and the differential GPS (DGPS) device. Standard GPS and DGPS differ from A-GPS in that the former are technologies, and the latter is a method for processing the data generated from a GPS device. The FHWA review of GPS in transportation stated that the differential GPS device is more accurate that the standard GPS, but Yim and Cayford show that the difference is not significant. The GPS is accurate to 15 meters (49.2 feet) while the differential GPS is accurate to 10 meters (32.8 feet). The field operational tests indicate that this 5 meters (16.4 feet) difference is not significant. The DGPS was tested on 62.4 kilometers (38.77 miles) stretch of highway. 58.3 kilometers (36.23 miles) of the 62.4 kilometers of highway were identified for a 93 percent success rate. The success rate using GPS was 92 percent. This result shows that the difference between the DGPS and GPS are not significant.

Although Cayford and Yim found high success rates with the technology, problems using GPS do exist, as identified in the Washington TRAC studies. The problems most associated with collecting GPS data for calculating travel time are that the GPS devices are not carried by most trucks, transferring data from a private entity to a transportation agency can be problematic, and drivers are skeptical that their privacy would be protected (McCormack and Hallenbeck, 2005). Furthermore, even with the accuracy of these devices being 10 and 15 meters (32.8 and 49.2 feet respectively), differentiating frontage roads from freeways is difficult.

The 2003 TRAC study tested a different scenario than that adopted by the FHWA/ATRI work. The area of analysis was within the Seattle urban region, which is also monitored by a loop detector system. Three trucks had GPS devices installed in the cab and were tracked for a 9-month period. Information provided by the GPS device included vehicle speed, time, travel direction, and location. The small number of test vehicles led to a limited spatial and temporal coverage of the freeway system. Just as with the transponder technology, a large number of vehicles equipped with the GPS devices is needed to provide an accurate understanding of traffic conditions on a freeway.

Not only is a large fleet desirable, but frequent readings from the vehicles are also beneficial. The FHWA/ATRI work received information on the location of a truck based on carrier policy. GPS devices used by carriers for tracking vehicles are typically queried every 1 or 2 hours during normal operations, but the trucks being used as a traffic probe in the TRAC pilot test were queried more often. The researchers state that receiving location information every 1 to 2 seconds is ideal for vehicle probe uses; however, the high costs of collecting data prevented such a frequent recording strategy. The research team decided to take readings every 2 minutes. The cost necessary to provide readings every 2 minutes for 16 hours a day and 100 trucks was $140,000.

Different reporting times of 2 or 3 minutes were implemented. The difference of 1 minute in reporting time led to lower costs but resulted in a lower quality of traffic information. In the urban environment, using GPS in vehicles requires a high frequency of reporting vehicle location, so the data gathered is similar to what can be obtained through loop detector sensor systems. Comparing the sensitivity of information between this study and the FHWA/ATRI work is intriguing, because the reporting time interval for trucks equipped with GPS devices is arbitrary in the FHWA/ATRI study. The reporting period for trucks in the FHWA/ATRI study was set according to carrier policy and could range from 1 to 2 hours or could be set to report when trucks arrive at certain locations. If the reporting took place every 1 to 2 hours, the spatial coverage of the data for describing truck mobility would be similar to that gathered through the use of transponders along I-5 in Washington.

The use of GPS data to produce real-time data may be limited because of the high cost of collecting, processing, and distributing data, but the FHWA/ATRI work has shown that GPS freight data has the potential to be effectively used for planning purposes. Freight performance measures identified by TRAC include average and 90th percentile travel times for specific roadway segments and corridors, frequent congestion on specific roadway segments, and images of the geographic spread of congestion by time of day (McCormack and Hallenbeck, 2005).

The research team from TRAC has also summarized the cost for using GPS in their studies. The cost for 4,500 reads a month was $60 per vehicle. When not participating in a study, the carrier would normally absorb the cost of the wireless charges to track the truck while in route. The transportation planning agency would then have to come to an agreement with the carriers on the acquisition of this information for the purpose of determining corridor travel times. The study figured that 150 to 200 GPS devices would need to be used to provide a comprehensive spatial coverage of the Seattle metropolitan area. Including the cost of the 150 devices ($625 per GPS device), start-up costs ($200,000), and data processing costs ($150,000), the total cost for the Seattle area would be approximately $475,000.

Using GPS to provide travel time information has its advantages. First, the coverage area is more flexible than that provided with DSRC networks, and many fleet vehicles operating in Texas are equipped with GPS devices but not as part of a program driven by a regulatory agency. GPS freight data may be more readily available to implement, but because trip segments produced by GPS queries are not fixed between trucks, the processing of data for all highways and interstates could be burdensome. Furthermore, the long term commitment of carriers to participate in a program that provides travel time information to a transportation agency has not been determined. This uncertainty might be reason enough to support initiatives for the state to develop its own freight data programs generated from electronic clearance or tolling programs.

Clearly there are several different types of locational technologies to be considered for freight vehicle monitoring. Study 0-5410 assisted TxDOT consideration of FPM adoption in its planning activities by holding a mid-year workshop for TxDOT staff. This workshop was designed to show developments in the field of FPMs, revealed by the study and CTR research staff, together with TTI researchers working in the area of urban performance, stimulated discussions with state planners. The workshop was strengthened by the willingness and generosity of FHWA and ATRI staff that traveled to Austin to make presentations on their programs, results, and future plans. This workshop is the subject of the next chapter.

5. CTR Workshop and Texas Data

5.1 Introduction

Texas has several freight-significant corridors crossing through the state; two corridors, I-10 and I-45, were included in the early analysis conducted by the FHWA and ATRI. Because these corridors were a part of the study, CTR contacted representatives from both institutions to participate in this scoping study through a workshop held on May 12, 2006. In preparation for that workshop, Jeff Short from ATRI visited CTR on April 13 and 14, 2006, to review Texas FPM data on I-10 and I-45. During this visit, researchers from CTR were able to review the data and gain a more thorough understanding of the methodologies used by ATRI to calculate FPM for average speeds. The following sections review the methodologies and showcase some of the Texas examples derived from the data collected in Phase 3 of the FHWA and ATRI partnership.

5.2 Data Manipulation

The data available to ATRI from the vendor is accessible only in very large text files with one line for each time any individual truck in the specified corridors is "pinged." *Pinging* refers the GPS unit being contacted, either because of regularly timed polling or human-controlled polling for any number of reasons. Each line of data contains the truck ID of the pinged vehicle, the date and time of the data point, the latitudinal and longitudinal coordinates of the truck location, and the highway the truck was on. There are a number of problems associated with the form in which the data is collected.

One problem is the accuracy of the GPS system. Each data entry has a location that is accurate to within ¼ of a mile. Over long periods, this range of accuracy is not a problem, and with large aggregations of data, it tends to make little difference. However, with two data points of the same truck collected close in time, the inaccuracy could result in some odd data, even occasionally resulting in two data points showing movement in the opposite direction of actual movement. For this reason, ATRI made a practice of dropping any two fields that are less than 15 minutes apart. Another possible drawback of this slight inaccuracy is that while the data was collected with a buffer intended to exclude highway frontage roads, this exclusion is not guaranteed. Inclusion of frontage roads could give skewed results, particularly in times of high congestion.

Another problem with the data is that stoppages that are not the result of a highway system failure are difficult to separate from those that are due to congestion. A truck stopping for fuel or for a rest break can appear as a very slow-moving vehicle after data analysis. The solution tested by ATRI was to drop data points with very little distance traveled between two data points compared to other trucks on the same highway over the same time period. This appears to be a successful solution, although it needs to be taken reluctantly and with care. Given the current data collection methods, no one solution can completely alleviate this problem. It will always be inherently possible to eliminate low speeds resulting from nonrecurring delay while trying to eliminate readings taken from vehicles that are stopped for a fuel or rest break. The current practice of eliminating those data points with speeds below one standard deviation may be successful in broadly examining average speeds, but this is not appropriate if the data will be used to measure variance and reliability of the highway network.

One of ATRI's most important implementations in the manipulation of this data is the development of their "snapping algorithm." This algorithm was implemented through a program that took the precise GPS coordinates for the location of a truck, albeit with some degree of error, and used the nearest coordinates on the National Highway System (NHS) to the GPS recorded coordinates to represent the collected GPS coordinates. This step was necessary if the data was to be used graphically because the GIS maps created by ATRI used the NHS coordinate system and highway network. This transformation of the GPS collected data is necessary because data display of freight conditions is one of the key goals of FPM development. Along with this snapping process, the program converts truck-specific IDs to a random identifier unique to each truck, which makes the truck positions anonymous and unidentifiable with any specific motor carrier company. Realistically, this anonymity is essential in acquiring any information on truck locations.

5.3 ATRI-Suggested FPMs

There are many potential uses for the GPS data collected for the study, but ATRI began by focusing mainly on average speeds. This was accomplished using the simple algorithm of finding two data points with the same truck ID, finding the distance traveled by subtracting mile markers, and dividing by the elapsed time. Since non-speed measures are not considered, all data points not corresponding to two unique positions of a single truck are eliminated.

Throughout the alpha and beta tests of the study, it was assumed that due to the standard hourly polling of trucks, a 50-mile minimum segmentation of the highway was necessary. This reasoning is accurate for single trucks. However, as truck location records increase over a corridor, average speed calculations could be found over a shorter distance. Since the publishing of the last paper on their work, ATRI has begun to evaluate speed over distances as short as ten miles and is looking into segments as small as a single mile. This development is an important point because transportation planning agencies will have access to more precise planning information as the length of freeway segments decreases from 50 miles to 10 miles.

After the beta-testing phase of this project ended, the number of corridors being evaluated by ATRI/FHWA increased from the original five corridors to 25 corridors. Together with the segmentation of data into smaller highway intervals, this has enabled the use of GIS software for the visualization of average speeds on a scale not previously possible. While ATRI has yet to propose any specific FPMs, the maps they have begun to produce showing speeds in various situations clearly show the usefulness of this information.

The simplest way to look at speeds on a corridor is to show average speeds on individual segments by time of day. Figures 5.1 and 5.2 show the average speeds calculated by ATRI on segments of highway in Texas at two different times of the day: one for midday, when trucks on the highway segments are flowing at approximately free-flow speeds; and the other at the p.m. rush hour. As expected, most intercity stretches of highway are relatively unaffected by rush hours; the largest congestion effects occur in segments lying near or within major cities.

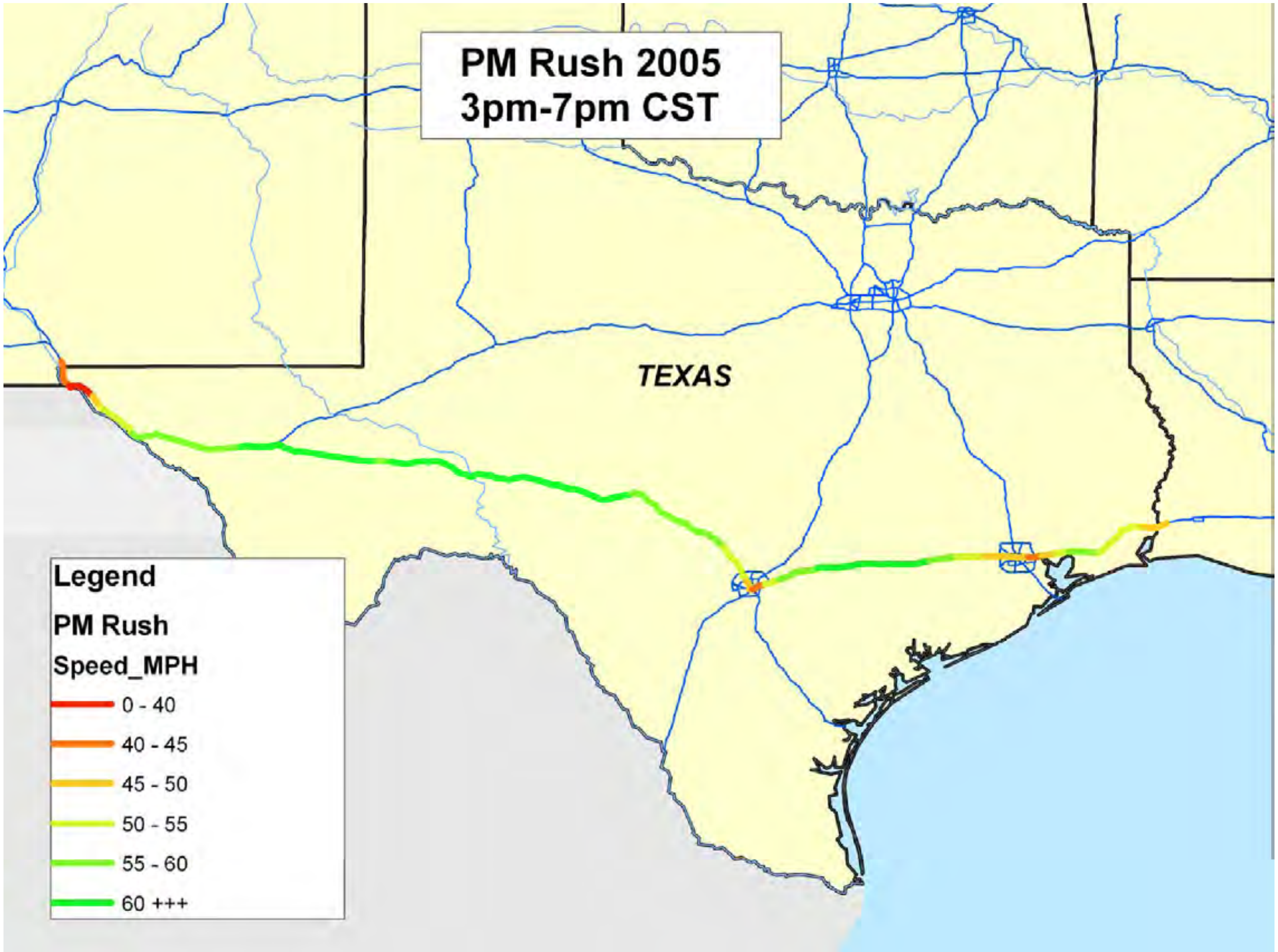

Figure 5.1: P.M. Rush Highway Speeds for 2005
Source: Short, 2006

Figure 5.2: Free-flow Highway Speeds in 2005
Source: Short, 2006

As this technology progresses and obtains more robust data sets, these maps could be produced for each hour of each day, possibly self-updating for real-time use on the internet or highway displays, or simply for planning and performance measurement use. Throughout the brief span of analysis that this data has seen, it has already shown its usefulness for nonrecurring delay and disaster purposes, particularly in identifying bottlenecks. Figures 5.3, 5.4, and 5.5 show the "Texas triangle" area of the Texas highway system on September 20, 21, and 22 (2005), and the ATRI-calculated average speeds on each highway segment. These dates correspond to the days immediately after the Hurricane Rita evacuation was announced. During this period, certain bottleneck sections of the highways were almost at a standstill.

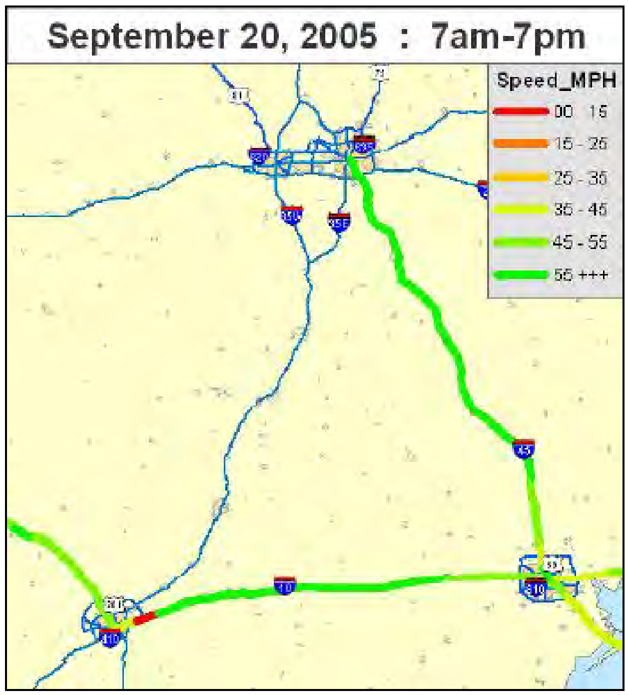

Figure 5.3: Disaster-Related Congestion
Source: Short, 2006

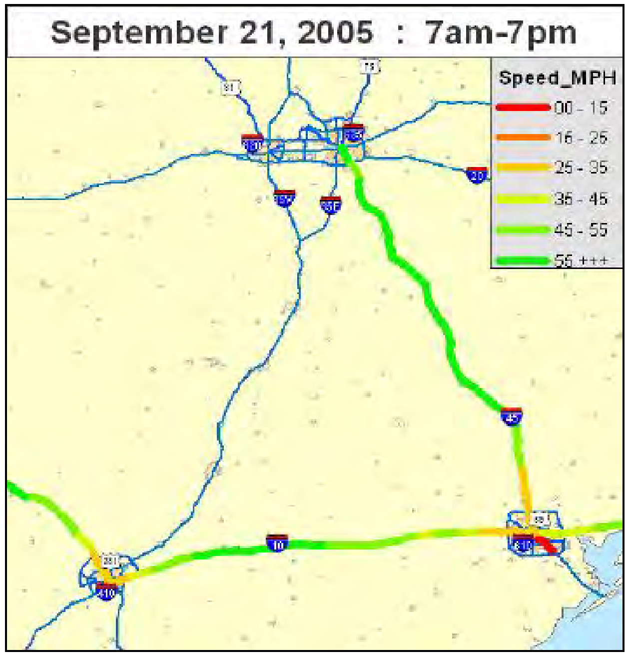

Figure 5.4: Disaster-Related Congestion
Source: Short, 2006

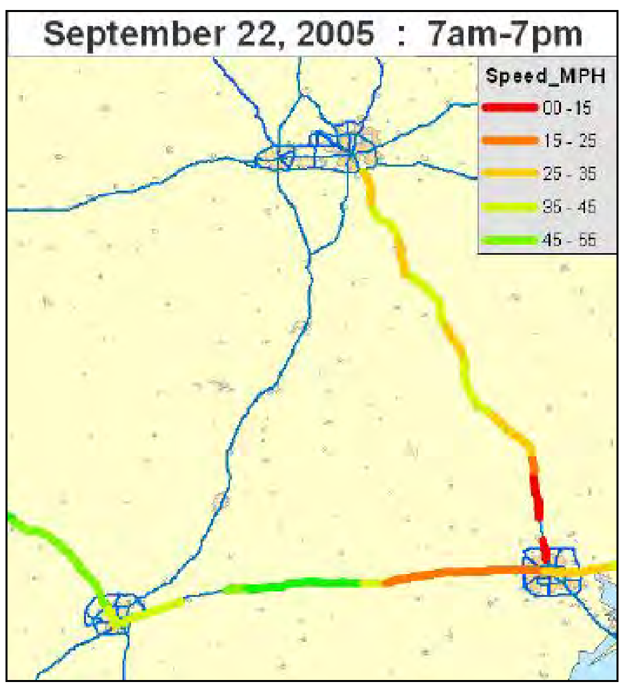

Figure 5.5: Disaster-Related Congestion
Source: Short, 2006

While most of this research has focused on average speeds, some reliability measures are underway, mainly focusing on using the TTI Buffer Index along entire state segments of each highway. This work provides a decent state-to-state comparison of travel time reliability, but as yet has provided no comparison on a smaller scale for the use of state planning organizations.

5.4 Utilization of the ATRI Data in a Texas Case Study

For 2 days in mid-April 2006, Jeffrey Short from ATRI visited the Center for Transportation Research to collaborate on new ideas for the application of the GPS truck data into freight performance measures, specifically related to Texas highways as a case study. The visit generated many ideas for potential future work with the data and possible measures. One application in particular—finding an hourly volume of traffic throughout the day—was looked at in detail and yielded preliminary results and explicit ideas for future use of the measure.

The typical distribution of total traffic throughout an average day is quite similar from city to city. There are two major peaks, one in the a.m. and a longer one in the p.m. rush hour, and a broad assumption can be made that in either one of those hours, 10 percent of total daily traffic volume occurs. It is also assumed that the p.m. peak tends to sustain volume longer than the a.m. peak both before and after the highest hour. Also, in terms of total traffic, the night-time volumes are a small percentage of total volume. Metropolitan areas often complete their own studies of hourly trip distribution to pinpoint the patterns of their cities. Figure 5.6, for example shows a typical 24-hour trip distribution for Austin, Texas created by the Austin Metropolitan Planning Organization.

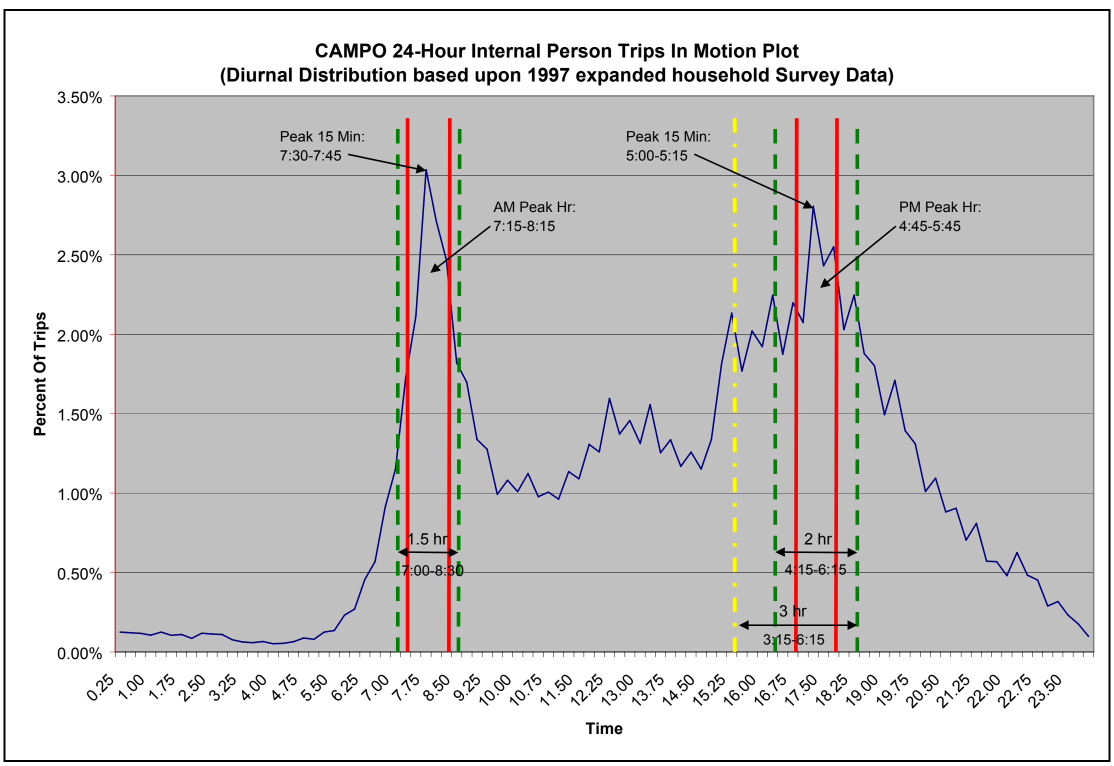

Figure 5.6: 24-Hour Traffic Volume Distribution of Austin, TX
Source: CAMPO

Often, truck traffic volume calculations are oversimplified for city or region-wide planning purposes. In many cases, a simple percentage of total traffic on highways is assumed to be truck traffic. This is generally based on broad observations, and while it may be accurate to assume a percentage over the timeframe of an entire day, it is not intuitive to assume that the decisions and priorities of trucking companies will be the same as passenger vehicle drivers. In the past, the reasoning for using this simplified information has been a lack of required information for proper truck volume estimates. Such information would be quite valuable to regional mobility planners for determining accurate truck travel patterns in their models. This could also be valuable to future investors in toll roads that consider congestion or time-of-day pricing, because current projections tend to be based on inaccurate assumptions.

In this capacity, the GPS data being collected by truck polling would be useful for supplying the lacking information on traffic distributions. Figure 5.7 shows hourly truck traffic distributions based on all 2005 traffic in four areas: a 2-mile stretch of I-10 in Houston just east of the outer loops, a 2-mile stretch of I-10 in El Paso just east of the border crossing, a 12-mile stretch of I-10 around the rural Texas town of Sonora, and all of I-10 in Texas. These four positions were chosen to contain all of the traffic on the I-10 corridor, which is why positions inside of loop highways were not chosen. Also, they provide a good mixture of urban and rural locations, as well as El Paso, where peak hour congestion is especially problematic due to border crossings.

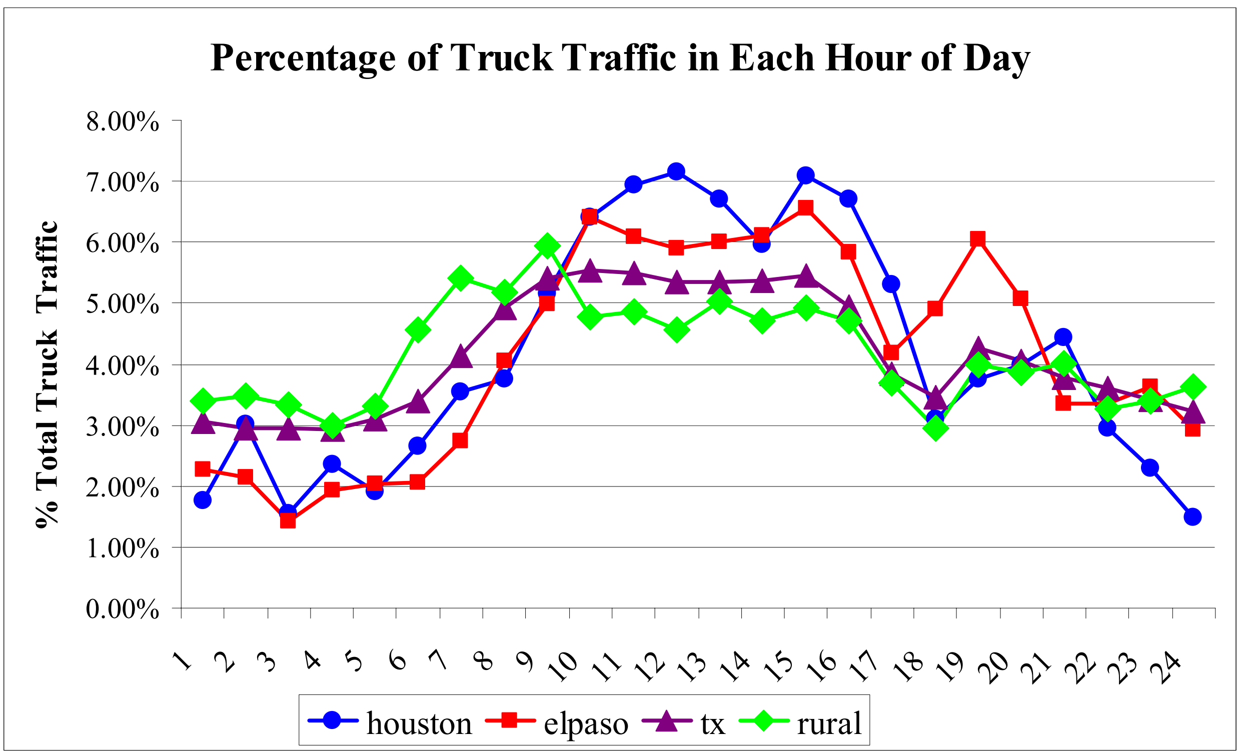

Figure 5.7: Hourly Truck Traffic Distributions Based on GPS data
(Created in conjunction with Jeffrey Short of ATRI)

Many conclusions can be drawn from these graphs. It is immediately apparent that trucks do not simply follow a flat percentage of total vehicle traffic volumes. As expected from companies that have experience operating on major highways, the trucks avoid the highways around normal peak periods and do the bulk of travel between 10 a.m. and 4 p.m. This is more noticeable in the urban areas of Houston and El Paso. The stretch of rural highway is much more evenly distributed, not fluctuating as much to time change, as would be expected because rural areas do not encounter the same congestion effects at peak hours. In fact, night-time travel by trucks in rural areas seems to be more than half that of day-time travel volumes, which is unheard of for passenger volumes, in which travel drops drastically at night.

It is important to note that while this estimation can work for percentages of trucks, it is not an accurate truck count, as it applies only to those trucks fitted with GPS units that supplied data for ATRI work and whose data was not eliminated for polling reasons mentioned earlier. However, because each of the four case studies had thousands of data points over the 24-hour period, it can be assumed that these samples could represent the truck population trends fairly well.

5.5 Further Work and Future Application of Data

Although there have been several years of work by ATRI in developing the data manipulation methods necessary for the GPS truck data and utilizing them to get useful results, the work is only recently moving from a preliminary stage to the kind of testing that should display the potential of this information. As the project comes into a secondary stage, there are numerous directions that could be followed for future application of the data.

Extensive speed measurement has been completed and displayed along many of the major U.S. corridors, as in Figures 5.1 and 5.5, but there has been no display of these speeds as a percentage of the free-flow speed for each segment. This is important when focusing on areas that have been shown to have a significant bottleneck, even at late night hours. Measuring unweighted average speeds along highway segments can help planners find bottleneck locations, but, until each segment is compared to its free-flow speed, it is difficult to determine both operations or locations of nonrecurring delay (like crashes). This goal would not require any additional changes in data collection or initial manipulation, because everything needed to accomplish this is currently at the disposal of ATRI.

On some large sections of the beta-test corridors, ATRI has looked at one measure of reliability, the TTI buffer index, but only for a corridor across each entire state. While this is a good preliminary step, it does little to show planners and users which individual sections within a state are the most unreliable. Decreasing the distance of the highway segments analyzed down to 10 miles and possibly a single mile in the future, efforts could be undertaken to display and project some form of reliability on these smaller segments. This method could be done either by using the buffer index or the Average Speed Reliability (ASR), discussed in Section 3.4 of this report. This ASR is simply the standard deviation of truck speeds traveling each segment, which is arguably a more widely understood measure of reliability.

The key performance measures evaluated in the FHWA/ATRI work are travel times and travel speeds. These measures are derived by identifying a vehicle and its precise location and then, after time elapses, identifying the same vehicle and its location again. Technology is needed to sense traffic traveling on a roadway, and four technologies tested in the literature include cellular phone tracking, GPS units, RFID tags, and loop detectors. The work done by FHWA/ATRI on truck travel time utilized location information generated from GPS units on board commercial vehicles. Similar in concept to GPS units but differing in performance, cellular phones are a second technology that can be used to track vehicles. GPS and cellular phone tracking both rely on satellites to locate vehicles, but according to field operational tests, the accuracy of these readings are not comparable. A third means for figuring travel times on a freeway is available by compiling RFID tag readings between two fixed points. The use of RFID tags in transportation is increasing as a result of electronic toll collection (ETC) and electronic screening used at commercial vehicle enforcement sites. Loop detectors are the final technology included in the previous list used to figure travel time. This technology is primarily used to measure travel time in urban networks.

The 1990s were the decade for initial technology testing to improve commercial vehicle operations. Several field operational tests were conducted, and a few of these included using GPS, cellular phones, and electronic tags technologies. The goal of these tests was not to determine travel times, but they had more prominent roles in facilitating the movement of commercial vehicles or improving the real-time detection and response to incidents. Since 2000, several tests were conducted to evaluate the usefulness of GPS, cellular phones, and electronic tags for purposes beyond those identified through experiments in the '90s. The primary investigation was the use of these technologies so vehicles could serve as traffic probes and travel times on a roadway could be determined.

The research team acknowledges that the FHWA/ATRI team has demonstrated as a proof of concept that GPS can be used to calculate average speed and travel times on a segmented roadway. The difficulty associated with acquiring GPS data from private companies concerned with the privacy of company information may make the use of other technologies to determine travel times more feasible. The use of cellular phone data would also require the acquisition of information from a private telecommunications company. The same difficulties associated with obtaining GPS data from a provider may therefore be true for cellular phone information. Because of these difficulties and the fact that other technologies are available, a review of field operational tests for GPS, cellular phones, and electronic tags was conducted to determine the application of these technologies towards freight performance measure strategies; however, the information from these data sources can still be beneficial to transportation decision makers. The emphasis of the FPMs is on intercity truck traffic. Since loop detectors are primarily used in metropolitan areas and not feasible for intercity data collection, they are not included in the following technology review.

5.6 Implementation of FPMs in Texas: Planning Benefits

Any type of vehicle location information from push-type delivery in passenger cars to GPS locations from motor carriers can be used extensively in performance-based planning and specifically in maintaining and using FPMs. Performance data is not particularly useful to planners if it cannot be displayed in a way that is intuitive, which is where the use of GIS packages can be most useful. With real-time information from vehicles, databases can be constantly updated and fed into GIS applications, giving a minute-by-minute view of the performance of a highway system. This system is not only incredibly useful for determining bottlenecks and crashes, but can also be helpful in spatially visualizing congestion as it changes throughout the day.

Another use of GIS packages in FPM planning is determining trends over a course of years that could then be used for forecasting future measures. Figure 5.8 shows a GIS-based representation of average delay in areas of New Jersey. This tool is a useful application of delay data that can be collected from motor carriers, either by area or by segment of highway. Representing the data graphically makes problem areas more visible for planners, toll road operators, and system users. Figure 5.9 shows a similar delay representation but is forecasted to 2025. This forecasting can be done not only by analyzing demand, but also by interpolating delay data from the past. This aggregation of annual data, more than any other method, can be used to determine future needs in the area to meet FPM goals. Figure 5.10 shows the simplest possible method for planners to determine what areas or segments need investment to meet goals, representing the **Needs = Goals – Performance** equation stated in Chapter 2. This strategy is the real purpose and future of FPMs because this result can show very accurately the problem areas not meeting PM goals and creates a plan on which decision makers can focus their attention.

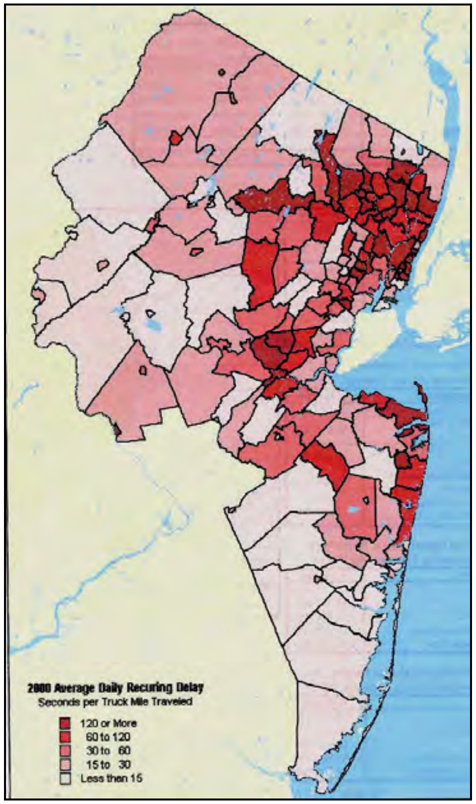

Figure 5.8: GIS Representation of NJ Delay—Current

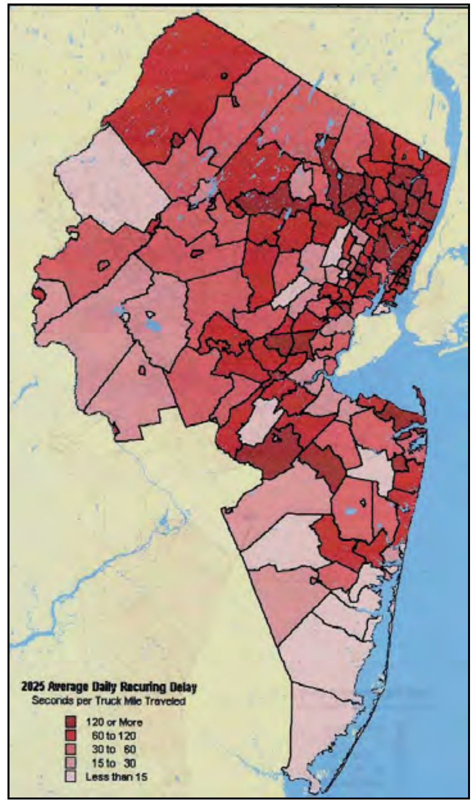

Figure 5.9: GIS Representation of NJ Delay—Projected

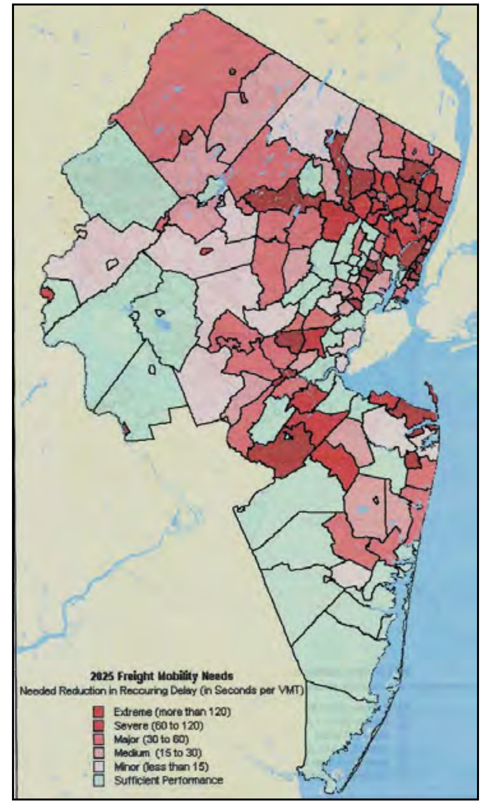

Figure 5.10: GIS Representation of NJ Future Mobility Needs

Source: NJIT, 2003

5.6.1 FPM Implementation for Congestion-Based Tolling

As mentioned previously, knowing the travel patterns of trucks in an average 24-hour period could be useful in determining tolling prices on highway segments. For example, the results in Sections 5.3 and 5.4 showed that night-time is somewhat of a down time for truckers, but not nearly to the extent of passenger travel, and a decrease in night-time tolls could be used as a variable-congestion strategy. The price difference with time of day would need to factor demand elasticity in setting such variable rate tolls.

Similarly, if real-time operations data becomes a reality, congestion-based pricing could be based on this constantly updating data, not from assumptions made at one preliminary point in time. In the case of a tolled bypass being added in an urban area, such as SH-130 in Austin, Texas, truck location data could determine the time savings resulting from taking the bypass as opposed to the main highway through the city. Not only could this time differential be displayed prior to the toll road ramp to promote its use and minimize overall delay, it could also be used real-time in determining an appropriate cost for using the road.

The only other information required for full congestion pricing would be the money value of time for users. Research has attempted to estimate the monetary value of time for passengers, with the FHWA reporting that the value of time in 2002 was $9/hour (DeCorla-Souza). In California, Steimetz and Brownstone have found the average passenger value of time to be $30/hour, with a range of $7/hour to $65/hour (2004). Although these values range with user perceptions and geography, determining the value of time for motor carriers has been more elusive, largely because of data sharing issues. If paper or electronic surveys are not well-received, GPS data could be the solution for this as well. At a variety of tested toll levels, the simple toll/non-toll decision of truckers could be used to form a discrete choice model which, when combined with knowledge of travel time, could determine the truckers' money value of time. This in turn could be used to calculate an appropriate toll to charge at any congestion level or time of day.

5.6.2 Real-Time ITS Possibilities

The greatest potential of using truck-based GPS units is the possibility of using the trucks as probe vehicles, not just for long-term planning purposes but also for real-time evaluation of traffic conditions. The potential uses for this real-time data were explained thoroughly in Chapter 3, but briefly, they include 1) display of up-to-date travel times on the highway systems, 2) opportunities for traffic-normalizing, where overall users in the system can be counted on to make optimal decisions, 3) nearly instantaneous incident location at traffic control centers, and 4) better route-planning for emergency vehicles, among others. The difficulty in accomplishing this is currently the result of data collection processes that update approximately every hour. If real-time ITS applications are to become a reality using truck GPS data, the trucks needs to be pinged continuously and, in turn, the data needs to be continuously transferred to whichever agency will be in charge of manipulating it. Beyond that, the data manipulation processes need to already be in place so there is very little lag between data collection and data analysis and display. Currently, the cost to process and present real-time data would be burdensome, but as methodologies improve, the system could be fairly self-sustaining and would offer users a service for the increasing fee they will be asked to pay for transportation systems use in the future.

6. Linking Intercity and Urban Corridors

6.1 Introduction

The ATRI data currently include both urban and rural areas, and there is no known distinction between them in the dataset. However, the urban area boundaries could presumably be identified so that the rural highway system would be covered by ATRI data, and one of the ongoing urban congestion programs could be used for urban areas. In smaller urban areas not represented by any of the urban congestion estimation programs, there would hopefully be minimal error in relying solely on the ATRI data, as long as speeds do not vary significantly from rural areas. The following bullet points summarize the positive and negative features to be considered in this task. The remainder of this chapter addresses these issues in more detail.

Some positive attributes of the ATRI Data:

- The FHWA/ATRI program gives a measure of FPM where virtually none has previously existed.
- It utilizes existing equipment that the motor carrier industry uses daily and is therefore not disruptive to normal motor carrier operations.
- It is flexible in that it can ping the trucks at selected intervals.

Some negative attributes of the ATRI Data:

- Privacy is a large issue, but ATRI provides a buffer to minimize carrier concerns. There will undoubtedly be privacy issues with any other sources as well.
- It is only a sample of long-haul trucks and does not consider local carriers or smaller carriers.
- It excludes cars altogether (for comparison with urban measures).
- It includes both urban and rural conditions, so slower urban speeds can be mixed with higher rural speeds.
- Little is known about how accurate the results are because there has been little verification.
- Cost may be an issue in terms of converting the data to travel time even though the process uses existing equipment.
- Delays in the data processing could be an issue for some desired applications, such as near real-time freight monitoring.

- If monitored trucks stop for a short time period (e.g., weigh stations, refueling, hours-of-service requirements, and deliveries), the technique may not detect the stop and will generate erroneous data for travel time estimation.

A general conclusion is that at the current ping rate, it is anticipated that the accuracy is relatively low. ATRI and FHWA are, however, well aware of this likelihood and the sampling rate may well be changed in subsequent phases of the study.

6.2 Current Urban Congestion Programs

There are three major urban congestion programs currently available for consideration in this project. This brief overview highlights some of the key differences in each and suggests how pertinent each might be in comparison to freight performance measures.

Mobility Monitoring Program—The MMP is a relatively new program, which began in 2001 with an analysis of 2000 data. It uses archived traffic detector data to monitor traffic congestion and travel reliability in cities that have the data available. The MMP uses direct measurements from roadway-based sensors that are used for real-time traffic operations. The total number of cities currently providing data for this program is 29, although the number is expected to grow. Its temporal coverage of data is continuous (24 hours per day, 365 days per year). The time lag in reporting of the data is 15 days for monthly reports and 6 to 9 months for the annual report. FHWA sponsors this program and sets the reporting requirements to support a monthly update for upper level DOT management (Turner, Margiotta, and Lomax, 2004).

Urban Mobility Report—The UMR program, which began in 1982, has been in existence for longer than the Mobility Monitoring Program and uses a different source of data. It utilizes section level data from FHWA's Highway Performance Monitoring System (HPMS) to produce an annual report on traffic congestion and its impacts in the 85 largest urban areas in the U.S. It does not measure speed or travel time directly but uses the average annual daily traffic (AADT) and number of lanes from the HPMS database as a basis for its estimates. It converts these estimates into congestion metrics using equations developed specifically for this purpose. Its temporal coverage of data is an annual average and the time lag for reporting is 18 months. Sponsors for this program are the American Road and Transportation Builders Association (ARTBA), the American Public Transportation Association (APTA), and the Texas Transportation Institute (Turner, Margiotta, and Lomax, 2004).

Urban Congestion Reporting Program—The UCR program began in 2002 and gathers current traveler information reports from websites and archives the data for use in monthly reports on traffic congestion and reliability in about ten cities. Its temporal coverage of data is weekdays (5:30 a.m. to 8:30 p.m.) and the time lag for reporting is 10 working days. The program has FHWA sponsorship and Mitretek support. This has been combined with MMP data (Turner, Margiotta, and Lomax, 2004).

6.2.1 Comparison of the Programs

The MMP provides the most detailed view of congestion in terms of both temporal and spatial coverage along with multiple mobility and reliability statistics—at least for the urban areas covered. It encourages states and local agencies to utilize archived data while using performance measures and optimizing quality control. Improvements to automation have reduced the reporting lag. The UMR provides only an indirect estimate of congestion on an area-wide basis and does not consider travel time reliability. Because of its reliance on HPMS, there is a substantial lag in reporting (18 months typical). On the positive side and given the UMR's longevity, it has established the longest trends of the three programs. The UCR has been able to produce the timeliest data of the three programs with its monthly congestion and reliability statistics. However, it is likely that the MMP will be able to match this frequency for more cities than the UCR program. The UCR program can include other roadway types besides freeways so it has that advantage over MMP, which is limited to freeways. Since the UCR program does not have traffic volumes available, it cannot produce total delay, so relative comparisons between cities can be misleading. Table 6.1 summarizes the three programs. As a matter of simplicity this task will focus only on the Mobility Monitoring Program, because its data originate in systems that measure speed directly, from which travel time can be derived (Turner, Margiotta, and Lomax, 2004).

Table 6.1: Key Features of National Performance Monitoring Programs

Feature	Mobility Monitoring Program	Urban Mobility Report	Urban Congestion Report
No. of cities in 2004	30	85	10
Years available	2000 to current	1982 to current	2002 to current
Source of data	Archived direct measurements of speeds, volumes, and travel times	HPMS (AADT, number of lanes, ITS deployments)	Travel times from websites (combination of reported travel times and TMC data)
Reliability measured?	Yes	No	Yes
Events monitored?	No, but weather and incident data planned	No	Incidents and weather (work zones planned)
Geographic coverage of data	Instrumented freeways	All roadways in urbanized area	Covered highways (mostly instrumented freeways)
Temporal coverage of data	Continuous (24 hours per day, 365 days per year)	Annual averages	Weekday (from 5:30 a.m. to 8:30 p.m.)
Geographic reporting (analysis) scale	Area-wide and directional routes	Area-wide	Area-wide
Temporal reporting (analysis) scale	Weekend/weekday; peak and off-peak periods	Average annual and total statistics	Peak period
Analysis timeframe	Annual; monthly for some cities	Annual	Monthly
Time lag for reporting	15 days for monthly reports; 6-9 months for annual report	18 months	10 working days

Source: Turner, Margiott, and Lomax, 2004.

6.3 The Mobility Monitoring Program

As noted previously, the MMP data that most closely relate to the ATRI data typically begin as spot speeds and volumes, which are then converted to travel times. The data collection devices used in the MMP run the gamut from inductive loops, to a variety of non-intrusive detectors, to automatic vehicle identification (AVI) tags in the case of Houston. Spacing of these detectors along the urban freeways varies from .5 mile to 1 mile or greater. The various technologies use a small fixed zone of detection, and the traffic speed and volume measurements are taken as vehicles pass through these zones. These initial estimates must then be converted to travel time estimates. Formulas presented later in this document indicate how to make this conversion. The temporal level of detail that is reported to the MMP varies by urban area, from 20 seconds to 15 minutes. Most archived data is available on a per-lane basis (if not per lane, then by direction) and the area coverage ranges from 6 percent to over 100 percent (some areas monitor freeways beyond the urban area boundary). The average coverage of freeway centerline miles is 46 percent. In several cities, the data do not currently cover all of the most congested routes for a variety of reasons, including reconstruction.

The typical steps used by the cities providing archived data to the MMP are as follows:

1. Roadway detectors (e.g., inductive loops, video imaging detectors, radar detectors) collect the data, which are stored locally. Roadside equipment transmits the data to a central location (usually a traffic management center, TMC) at 20-second to 2-minute intervals.

2. Some of the cities perform simple minimum and maximum range value checks.

3. Cities that use single inductive loop detectors can only measure volumes and lane occupancies directly. They must rely on speed estimation algorithms to compute spot speeds from volumes and lane occupancies.

4. Traffic Management Centers (TMCs) aggregate data to specified time intervals for archival purposes. These time intervals vary from 20 seconds (no aggregation) to 15 minutes. In some cases, the data aggregation converts per-lane data to data by direction.

5. The aggregated data are stored in text files or in databases and, in some cases, made available on CDs or DVDs.

The speed and count accuracy of these data probably vary considerably, and the precise accuracy level cannot be determined. One can only assume that the accuracy replicates that found elsewhere, based on tests of similar detectors compared against accurate baseline systems, although some of those tests were performed under near ideal conditions. Accuracies depend largely on the detection technology selected and also on how well they are maintained and calibrated. If properly installed and maintained, inductive loops are still overall the most accurate detection system in use today, usually achieving count and speed accuracy in the 95 percent or better range. The newer non-intrusive detectors have advantages over inductive loops to offset what is often a modest reduction in accuracy. Even in ideal conditions, these newer detectors might not achieve the accuracy of properly installed and maintained loops. Speed accuracy ranges for these systems often approach that of inductive loops, but their count accuracies may drop to 85 to 90 percent of true values because of weather or lighting conditions or due to occlusion by other vehicles, especially in very congested traffic (Middleton and Parker, 2002).

Even when properly installed, lack of adequate calibration and maintenance over time will compromise the data quality coming from operating agencies. Operators generally do not have the necessary resources to continuously check the data collection systems, and in many cases, allow lower tolerances to become acceptable. Therefore, the accuracy values for poorly maintained detectors could be even worse than those stated earlier. In the case of inductive loops, failures or lesser problems may not be addressed in a timely manner if the correction requires traffic interruption. This maintenance is often postponed to coincide with other roadway activities that also require lane closures.

Errors in speed and count estimates translate directly to errors in travel time estimates. Errors are typically fairly random in nature with some positive and some negative when compared to true values. Lack of calibration can also lead to a systematic bias in the data that may go undetected for an extended period of time. Some extreme errors in a dataset will be detected by error checking but most of the lesser errors remain. These archived data form the basis of many decisions and are the ones that are available to use in freight performance monitoring.

The MMP processing of data requires using measured spot speeds to estimate travel times. Figure 6.1 illustrates the process used by MMP of converting lane-by-lane speeds and volumes to freeway route travel times and vehicle-miles of travel (VMT). The steps are as follows (Turner, Margiotta, and Lomax, 2004):

1. The lane-by-lane data are typically combined into a “station” covering all lanes in a direction. This requires summing volumes across all lanes and developing speeds that are a weighted average based on respective traffic volumes.

2. Estimate link properties based on station data by assuming each detector has a zone of influence equal to half the distance to the adjacent detectors. Assume speeds are constant within each zone of influence, so calculate travel times based on equivalent link lengths. Use traffic volume to similarly calculate VMT.

3. Group freeway links with other similar adjacent links into analysis sections typically 5 to 10 miles in length. The termini of analysis sections typically coincide with major highway interchanges or with major changes in traffic or roadway conditions.

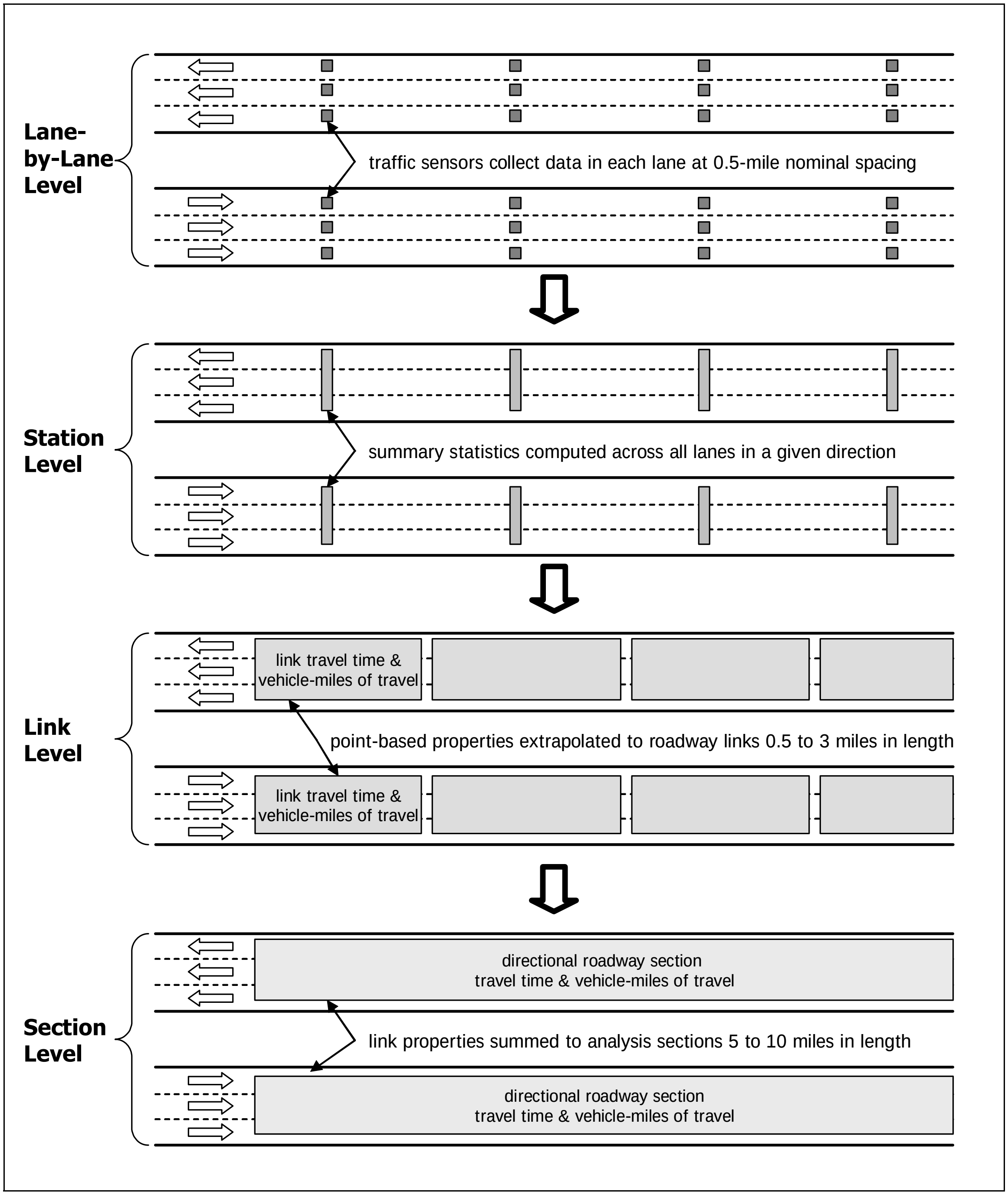

Figure 6.1: Estimating Directional Route Travel Times and VMT From Spot Speeds and Volumes

Source: Reference (2)

Travel times for these analysis zones served as the basis for subsequent mobility and reliability measurement calculations. Other considerations were as follows:

1. The data only included mainline freeway data (no ramp data).

2. Daily time intervals were early morning, morning peak, mid-day, afternoon peak, and late evening.

3. Major holidays were excluded from the weekday peak period analysis (atypical travel patterns) but included in some other daily statistics.

6.3.1 Congestion Measures

The Mobility Monitoring Program uses three measures to track traffic congestion. The measures—travel time index, percent of congested travel, and total delay—represent the average and total levels of congestion. Most applications report these measures for the peak periods (6 a.m. to 9 a.m. and 4 p.m. to 7 p.m.).

Travel time index. The travel time index is the ratio of average peak travel time to a free-flow travel time. The MMP uses free-flow travel times based on a speed of 60 mph. Index values indicate the length of extra time spent during a trip. For example, a value of 1.20 means that average peak travel times are 20 percent longer than free-flow travel times. The MMP calculates travel time index for directional freeway sections then combines them into an area wide average by weighting each freeway section by respective VMT. Equations 1 and 2 indicate these relationships mathematically (Turner, Margiotta, and Lomax, 2004).

.

For a specific road section and time period :

Equation 1

$$\begin{matrix}\textit{Travel time index} \\ \textit{(no units)}\end{matrix} = \frac{\textit{Average travel time (minutes)}}{\textit{Free} - \textit{flow travel time (minutes)}}$$

For several road sections and time periods :

Equation 2

$$\begin{matrix}\textit{Average travel time index} \\ \textit{(no units)}\end{matrix} = \frac{\sum_{i=1}^{n} \left(\textit{travel time index}_n \times VMT_n\right)_{\textit{each section and time period}}}{\sum_{i=1}^{n} \left(VMT_n\right)_{\textit{each section and time period}}}$$

Percent of Congested Travel. The percent of congested travel is the ratio of congested VMT to total VMT. The MMP uses a speed value of 60 mph, below which VMT is considered to be congested. Equation 3 indicates the percentage calculation.

$$\text{Percent of congested travel (\%)} = \frac{\text{congested VMT}}{\text{total VMT}}$$

Equation 3

Delay. Delay is defined as the additional travel time when actual travel times are greater than free-flow travel times (expressed as either vehicle-hours or vehicle-hours per 1,000 VMT). Equations 4 and 5 are expressions of delay *(Source: Mobility Monitoring Report, 2003).*

.

For a specific road section and time period :

$$\underset{(\text{vehicle}-\text{hours})}{\text{Delay}} = \frac{\left(\underset{(\text{minutes})}{\text{Average Travel Time}} - \underset{(\text{minutes})}{\text{Free}-\text{flow Travel Time}}\right) \times \text{Traffic Volume (vehicles)}}{60\ \frac{\text{minutes}}{\text{hour}}}$$

Equation 4

For several road sections and time periods :

Equation 5

$$\underset{(\text{vehicle}-\text{hours})}{\text{Total Delay}} = \sum_{i=1}^{n} \text{Delay}_n$$

6.3.2 Reliability Measures

In addition to the average and total statistics on congestion, there is a need to track variability of congestion and reliability of travel. Two measures—planning time index and buffer index—serve this need. The planning time index is defined as the 95th percentile travel time index; it represents the extra time that travelers should add to *free-flow travel time* to arrive at their destination on-time for 95 percent of their trips. The buffer index is the extra time that travelers should add to their *average travel time* when planning trips. Both the buffer index and planning time index are expressed as a percentage. Equation 6 defines the buffer index for a specific road section and time period (Turner, Margiotta, and Lomax, 2004).

For a specific road section and time period :

Equation 6

$$\text{Buffer index (\%)} = \frac{\begin{matrix}95^{th}\text{ percentile travel time} \\ \text{(minutes)}\end{matrix} - \begin{matrix}\text{average travel time} \\ \text{(minutes)}\end{matrix}}{\begin{matrix}\text{average travel time} \\ \text{(minutes)}\end{matrix}}$$

Selection of the road section and time interval should be chosen carefully to represent the reliability of interest to the analyst. For example, reliability in an urban area would probably consider freeway sections 5 to 10 miles in length with endpoints at major interchanges. Reliability for an intercity trip would consider much longer freeway sections whose endpoints correspond to cities, intermodal or freight centers, or other points of interest. Selection of time intervals should include conditions of a similar nature and interest to travelers. For example a buffer index for commuters should focus on periods of the day when commute travel is made and should not mix travel times from non-commute periods nor mix morning peak with evening peak travel times. Equation 7 provides a means of calculating buffer index values and average planning time across several road sections, time intervals, etc. using the VMT as a weighting factor (Turner, Margiotta, and Lomax, 2004).

For several road sections and time periods :

Equation 7

$$\text{Average index value} = \frac{\sum_{i=1}^{n} \left(\text{index value}_n \times VMT_n\right)_{\text{each section and time period}}}{\sum_{i=1}^{n} \left(VMT_n\right)_{\text{each section and time period}}}$$

6.3.3 Other Considerations

The MMP 2003 report encourages readers not to use a single measure or index for all situations since there is no single best performance measure. Each performance measure addresses different dimensions of traffic congestion and reliability. The report encourages the use of a “dashboard” approach where the use of multiple appropriate measures (minimum two or three of the five discussed in this document) are better than choosing only one. There is also no single time period that will be correct for all analyses. The travel time index values reported in the MMP report are peak period averages for all non-holiday weekdays.

6.4 Possible Linkages between ATRI and MMP

Investigation of potential linkages between the ATRI program and the MMP implies that there is value to be added by using results of the urban program as opposed to completely relying on the ATRI methodology for freight performance monitoring. The comparison requires close scrutiny of what each program measures and the indices that are output from each. Table 6.2 is a summary of some selected characteristics that provides a comparison of the two programs. Some of the values are estimates since some of the basic information is unknown but can be estimated based on other sources.

Table 6.2: Comparison of ATRI and MMP Characteristics.

Characteristic	ATRI	MMP
Vehicles monitored	Long-haul trucks	All traffic
Geographic coverage	Urban and rural - 25 interstate corridors	Urban only, 29 urban areas
Temporal coverage	Continuous, 365 days	Continuous, 365 days
Monitoring technique	Satellite	Point detectors
Variable initially measured	Location (lat-long)	Spot speed
Initial sample spacing	1 hour directional (about 50 miles apart)	½ to 1 mile every lane
Estimated travel time accuracy	80% to 90%	85% to 95%
Process used to convert to travel time	Highway distance divided by time difference	Convert to links of 5–10 miles long
Events monitored	None	None, weather and incidents planned
Peak-Off-peak reported	No	Yes
Holiday adjustment	No	Yes
Primary indices used for measuring congestion and reliability	TTID, BI	TTID, % congested travel, total delay, planning time index, BI

The first and perhaps most obvious difference in the two programs pertain to the vehicles being monitored. For freight performance monitoring, trucks are the target vehicles but none of the urban programs currently make a distinction by vehicle type. Some of the MMP urban areas count the number of trucks or at least calculate the percent of trucks but do not calculate their speeds separately and store it with other archived data. In recent research by Eisele and Rilett (Eisele, and Rilett, 2002), Houston and San Antonio freeway truck speeds were found to be significantly slower than car speeds. The Houston study found average differences in travel time estimates of 6.4 percent during congested conditions, while in San Antonio results showed the largest difference of 5.6 percent but under free-flow conditions. Intuition would suggest that there are reasons to expect truck speeds to be slower than non-truck speeds, especially in urban areas, due to differing vehicle operating characteristics. Factors that contribute to a difference in speeds include grades, locations requiring acceleration (trucks accelerate slower than cars), lane restrictions for trucks, and differential speed limits between trucks and cars. Trucks are simply not as maneuverable, especially in heavy traffic, as non-trucks so they cannot as easily take advantage of gaps in the traffic stream. Another vehicle-related question with the ATRI program is whether local trucks should be included in the dataset (satellite usage probably minimal), since the current program only includes long-haul carriers. While it is anticipated that there would be differences between long-haul and local carriers, the omission is not considered a big problem. Apparently, smaller carriers were also omitted from the dataset but the effects of that omission are unknown.

The ATRI program currently uses a "ping rate" of approximately one hour. For rural areas, which have fairly constant speeds and no serious impediments to travel, this rate may be acceptable. However, unpredictable disturbances in free-flow even in rural areas such as incidents, localized severe weather, or major traffic generating events could be masked at this frequency. Also, today's trucks haul more less-than-truckload (LTL) freight than a few years ago, requiring multiple pick-up and multiple delivery points. These stops could be short enough in length to be masked by the current one-hour ping rate. Stopping for refueling or an enforcement delay might also be short enough to be masked. Both the temporal and spatial measurement frequencies need to be investigated to determine how much improvement in accuracy can be gained for incremental reductions in ping intervals.

The ATRI program is corridor based whereas the MMP is not, although the MMP data start as point sources, which are then aggregated into freeway segments. Presumably, these segments could form a corridor that would be compatible with the ATRI emphasis. Given that origins and destinations in urban areas and even pass-through trips will likely require the use of multiple corridors, the process would also need to consider multi-corridor routing. This feature will add significant complexity to the MMP, so its feasibility will need to be investigated.

The "estimated travel time accuracy" provided in Table 6.2 from each program is nothing more than a best estimate on the part of the researchers. In the case of the MMP, accuracy is based on other sources that have investigated the accuracy of point detectors. However, these sources used conditions that were closer to ideal than the real-world data used in the MMP and derived from detectors that were not necessarily well maintained and calibrated. The ATRI data would approach its highest accuracy where there are no disruptions in the truck speed between pings. Its worst accuracy would probably occur where undetected disruptions were masked by a sparse sampling rate, but the delay would not be sufficiently severe to cause the data to make them appear anomalous. Since the ATRI process is relatively new, it should be verified by an independent party to the extent that is feasible. However, developing good baseline data will be challenging due to accounting for short-term delays such as incidents, special events, work zones, hours of service compliance, and effects of recurring congestion (e.g., urban areas).

The development of a linkage between ATRI and MMP will require the use of similar (or at least compatible) congestion measures and reliability measures. Since both the ATRI and the MMP develop travel time index and buffer index values, these two metrics would seem to be a good starting point. However, it would also appear that the ATRI calculation of TTID is slightly different from that calculated by the MMP. The MMP uses observed average travel time <u>during the peak period</u> divided by free-flow travel time to calculate the TTID. The ATRI methodology, on the other hand, apparently does not make a distinction between peak and off-peak periods in calculating the TTID. This observation needs to be verified, but if true would yield different answers.

6.5 Other Potential Sources of Travel Time Data

ATRI data may not always be available, so there is a need to investigate other potential sources of FPM data. At the present time these other sources are probably no more reliable or more accurate than satellite data and they may not currently have the necessary coverage and/or may require further development before implementation. This discussion should also consider the use of multiple technologies to achieve the desired coverage. As discussed earlier in this report, options include radio frequency identification (RFID), cell phone tracking, and the Vehicle Infrastructure Integration (VII) initiative. One of the MMP urban areas—Houston—already uses RFID to monitor travel times. Its application in rural areas would require expensive installation of RFID readers along major routes, so it might not be practical everywhere. Some of this rural need may be met in the future as tolling becomes more prevalent and its use of RFID readers in rural areas. Cell phone tracking seems to have abundant potential, but issues of accuracy and cell tower down time still plague this application. As GPS functionality becomes fully integrated into cell phones, it might become sufficiently accurate for freight performance and other applications. The current phase of the FHWA/ATRI study is exploring the use of other technologies such as electronic toll collection and weigh-in-motion equipment to supplement GPS measurement.

6.6 Conclusion

This investigation of linking ATRI data with MMP data at this point in the development of the ATRI method leaves several questions unanswered but at least identifies some key issues that need further investigation. Linking ATRI data with urban data assumes at the outset that there is value added by combining MMP or other urban program data with ATRI data. In fact, the MMP results are probably more accurate than the ATRI urban data, but that has not been verified. The accuracy numbers cited in this document are only estimates and both programs need further verification.

The strength of the MMP data is that spot speeds are measured directly and at fairly close spacing (1/2 mile to 1 mile). However, the current inability to capture truck speeds separately is a significant issue. Trucks have different operating characteristics making their speeds slower and travel times longer, at least in urban areas. Since some of the urban areas participating in the MMP have the ability to identify trucks (based on vehicle length) and therefore to collect truck speed data, it might be worthwhile to determine whether they would be willing to do so. That change would strengthen the case for using MMP data for FPM purposes.

An alternative to using one of the urban program's results might be to simply increase the ping rate of the ATRI process in urban areas. Further investigation needs to be considered to determine the feasibility of this option. The costs of such an increase along with continued long-term availability of the ATRI data would need to be investigated.

Privacy will be an issue for any technology. There must be a satisfactory means of stripping carrier identity from the data. It would appear that the minimum indices that should be considered for linking the ATRI and MMP data would be the travel time index and buffer index, as long as they are consistently defined in both programs. The methodology for interfacing the two systems at the urban area boundary needs to be worked out but GPS should be able to identify these boundaries. Converting MMP values to corridor-specific values appears to have merit but needs further investigation.

7. Conclusions & Recommendations

7.1 Study Overview

This one-year scoping study met all of its stated objectives. The review of current FPM work revealed several state and federal initiatives, and led to the team working closely with ATRI staff in determining Texas-based FPM data. The collaboration enhanced our work and hopefully was useful to ATRI in their endeavors. Also important was the study workshop held in May 2006 for TxDOT planners, when ATRI and CTR staffs were joined by FHWA staff to present the current status of freight PM work in the U.S. This milestone in the project served not only to structure the remaining work on the study 0-5410 but also prepared TxDOT staff for ATRI interviews undertaken one month later as part of their current FPM work. The chosen method by ATRI is but one of a number of potential technologies; this study addressed—but did not evaluate—the various alternatives. Finally, the TTI research team considered the issues to be addressed if the current mixed vehicle urban PMs are combined with the corridor FPM of the type being undertaken by ATRI.

7.2 Workshop Recommendations

Scoping studies rarely develop detailed conclusions and 0-5410 is no exception. However, the collaboration did provide some rather unexpected results, which led the team to the following recommendations for TxDOT concerning FPM policy:

1. TxDOT planners should work with ATRI and FHWA to further refine their current FPM work. Feedback from the state planning community so far strongly indicates a desire to access the FPM data in a user-friendly, efficient fashion. This access is probably best undertaken through the development of a dedicated web-based system where FPM data can be unloaded and used by planners. The CTR-ATRI collaboration was possible only after a lengthy legal process to determine a nondisclosure agreement (NDA) that would satisfy the need to keep data secure and under ATRI control. Clearly, this would not work for TxDOT planners and a web-based process is preferable.

2. FPM work with FHWA and ATRI will also develop other related pieces of PM work that together will benefit the state. The Texas economy, as shown in the statewide analysis model (SAM), generates large volumes of truck trips that originate or are destined within the state boundaries. In addition, several important freight corridors carry international goods (including NAFTA traffic) and U.S interstate commerce through the state. FPMs allow these routes to be monitored and sharpen the focus of where limited state maintenance, safety, and construction funds should be best directed.

3. FPM technologies are becoming more available and sophisticated, and at a lower cost. The FPM data provided by ATA/ATRI is not delivered in near-real time, making it more appropriate for planning purposes. However, the speed of change in

the technology/cost/implementation relationship is such that within a decade there will be a capability for collecting and implementing real-time driver information system on freight corridors of the type currently seen only on urban systems. TxDOT should begin to prepare for this opportunity.

7.2.1 Linking Intercity and Urban Corridors

An important element of the 0-5410 study was the urban-corridor interface and the TTI team was eminently suited to undertake this work. The task arose because connecting urban PMs in some fashion to the corridor PMs, the resulting freight trip data—first for planning then operational purposes—would provide an insight into freight truck flows and improve freight planning in a variety of important dimensions. TTI has developed three urban congestion monitoring programs, the most prominent of which is the Mobility Monitoring Program (MMP). The MMP provides a detailed view of congestion in terms of both temporal and spatial coverage along with multiple mobility and reliability statistics, at least for the 30 urban areas currently covered.

The Mobility Monitoring Program uses three measures to track traffic congestion: travel time index, percent of congested travel, and total delay. These measures represent the average and total levels of congestion. Most applications report these measures for the peak periods (6 a.m. to 9 a.m. and 4 p.m. to 7 p.m.). The strength of the MMP data is that spot speeds are measured directly and at fairly close spacing (.5 to 1 mile). However, the current inability to capture truck speeds separately is a significant issue. Trucks have different operating characteristics, making their speeds slower and travel times longer, at least in urban areas.

Linking ATRI data with urban data assumes at the outset that there is value added by combining MMP or other urban program data with ATRI data. In fact, the MMP results are probably more accurate than the ATRI urban data, but both programs need further verification. An alternative to using one of the TTI urban program results might be to simply increase the ping rate of the ATRI process in urban areas. Such issues might form the subject of future research, perhaps undertaken after the freight corridor PM work has a wider coverage, acceptance, and utility within the state planning community.

7.2.2 Immediate to Medium Term Consideration

Trucking is such an integral element of freight transportation that FPMs offer TxDOT planners an important insight into how the state highway infrastructure is being used and a means to identify critical network segments that appear to constrain performance, as in the case of bottlenecks. FPMs also offer an insight into how trucking functions and what new elements of highway design or use might raise performance. The 0-5410 research team offers five recommendations for consideration by the department.

1. Continue TxDOT collaboration with FHWA and ATRI in the current FPM study. This will help frame the work to reflect planning concerns, including how FPM data may be accessed by state planning staff.

2. Recognize that the current FHWA-ATRI work provides valuable planning data over the interstate network being covered in their expanded study. There is still some way to go before corridor data can be used for operational activities but the time horizon is shortening as technology costs and processing times decrease. Planning data are

valuable, however, particularly when undertaking the economic analysis of potential corridor improvements. Moreover, the data generated from current information technologies (GPS, Transponders, and cell phones) are more likely to be relevant to planning.

3. Current technology for the national collection of FPM data can be order ranked as (a) global positioning systems (GPS)—typically fitted to trucks to enhance company efficiency, (b) transponders fitted for other reasons, such as the electronic number plate program (HELP), and finally (c) cell phones, used by the truck driver. However, when these technologies are related to current Texas conditions, the lower order is reversed and cell phones move ahead of transponders because the state does not participate in regulatory programs such as electronic clearance at weigh stations. An important new technology for Texas will be the state-wide use of Tx-Tags, which will enable space-mean speeds to be derived for corridor sections where readers have been installed to determine speed profiles. Systems such as this might first be installed along toll roads like SH 130 for testing and evaluation.

4. Finally, TxDOT might ask FHWA-ATRI to increase their ping rate near or in urban areas to establish whether an urban speed profile can be determined. In contast to the FHWA-ATRI program, the MMP monitors different vehicle types; both need some form of verification before an urban-corridor interface can be made. TxDOT could encourage this effort by including it as an element in future urban traffic research studies.

FPMs are important because they provide the agency supplying state highway infrastructure—in this case, TxDOT—valuable information about the performance of its assets as measured by the freight users, the "customers" of the agency. The 0-5410 scoping study demonstrated that FPMs can be utilized to enhance state transportation planning. The report began with a quotation on performance that is worth repeating, in summary form. If TxDOT does not measure highway performance, it will not only be unable to separate success from failure but it will lack an understanding on how to remedy the failures.

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