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AN ASSESSMENT OF EXISTING AND EMERGING TRAVEL SURVEY PRACTICES

(EXTRACTED PORTION FROM REPORT PREPARED FOR US DEPARTMENT OF TRANSPORTATION)

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Report

Data Collection in the Portland, Oregon Metropolitan Area

Travel Model Improvement Program
Track D. Data Research Program

Preparedfor

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1.0 Introduction

1.1 Portland, Oregon as an Example of Innovative and Comprehensive Data Collection

Important short-term and long-range improvements to trave1 demand forecasting systems are being developed both nationally as part of the Travel Model Improvement Program (TMIP) and within individual urban areas. These enhancements improve the accuracy of the predicted transportation choices. Of equal importance, these enhancements also improve the sensitivity of travel demand model systems to a range of potentially important transportation, land use, air quality, and infrastructure management policies. Implementation of these model enhancements, however, requires the existence of a variety of supporting household and transportation data necessary to estimate, calibrate, validate, and apply these improved models within a given urban area.

The Portland Metropolitan Service District (Metro) has undertaken a comprehensive and innovative data collection program to support the development of an improved travel demand modeling system. As a part of this data collection effort, Portland is one of the first urban areas in this country to undertake a region-wide home interview survey that is explicitly designed to support the development of a *new* generation of travel demand models. This case study describes the data collection program undertaken in the Portland area and the associated travel demand modeling system improvements that these data are intended to support

Recommendations are provided to help guide others undertaking similar data collection initiatives. Other areas can benefit from the data collection activities undertaken by Metro. It is an example of a successful program using state-of-the-art techniques. A series of coordinated surveys was conducted with the objective of supporting the region's transportation planning and travel demand modeling needs. At the same time, there are characteristics of the Portland urban area that may not be directly transferable or applicable to other regions. These include the size and attributes of the Portland metropolitan area, the responsibilities assigned to Metro, and the resources available for this work. Nevertheless, the Portland experience demonstrates the benefits that can be obtained through inter-agency cooperation and careful planning of a multifaceted travel data collection program

The core of Portland Metro's data collection program is a regional Household Activity and Travel Behavior Survey conducted during 1994 and 1995. This effort included a two-day household activity survey, supplemented by a smaller sample stated-preference survey. The stated-preference survey was designed to analyze potential reactions of individuals to possible urban design and Travel Demand Management (TDM) actions such as congestion pricing and the availability and price of parking. Although stated-preference modeling has been used extensively in market research and in long-distance travel demand modeling, such techniques are only now beginning to be applied for urban area travel demand analyses.

Experience has shown that case studies documenting the results of existing "good practice" are one of the best forms of transferring leading edge techniques from one agency or geographic area to other locations around the country. The 1994 collection of household activity and stated-preference data, and the associated planned model enhancements, represent the current state-of-the-art of travel demand forecasting within this country. The Portland Metro experience, therefore, constitutes an important point of reference for other urban areas and state departments of transportation. This case study provides descriptions of the data collection activities that were undertaken, including sampling, pretesting, survey design, and survey administration. Information also is provided on the estimated costs of the data collection activities and the utility of the data collection activities.

While the emphasis of this case study is on the 1994 Household Activity and Travel behavior Survey, it is important to understand Metro's existing travel demand model system and other elements of the data collection program to put the 1994 survey in context. To this end, the case study addresses other elements of the data collection program in a separate chapter and describes the existing travel demand model system in an Appendix. The data collection program illustrates issues such as interagency coordination and combination of data from different sources as well as the breadth of information used for travel demand modeling. Also important to illustrate is the use of a Geographic Information System (GIS) as an organizing and analytical framework for the collected data.

Portland's data collection activities provide an example of a comprehensive and innovative data collection program that supports good transportation planning practice and a highly-developed travel demand model system. This model system in turn supports a variety of transportation and land use planning activities and responsibilities (Figure 1.1). Data collection and model system refinement is an on-going process and this case study provides a snapshot of this process as of the fall of 1995.

1.2 Metro: Portland's Regional Government

The Portland Metropolitan Service District (Metro) is the directly-elected regional government and designated Metropolitan Planning Organization (MPO) for the Portland, Oregon metropolitan area, home to 1.4 million residents. The district comprises three counties and 24 cities, and is governed by a seven member Metro Council representing districts within Metro's jurisdictional boundaries (Figure 1.2).

Figure **1.1** Data Collection to Support Planning Activities

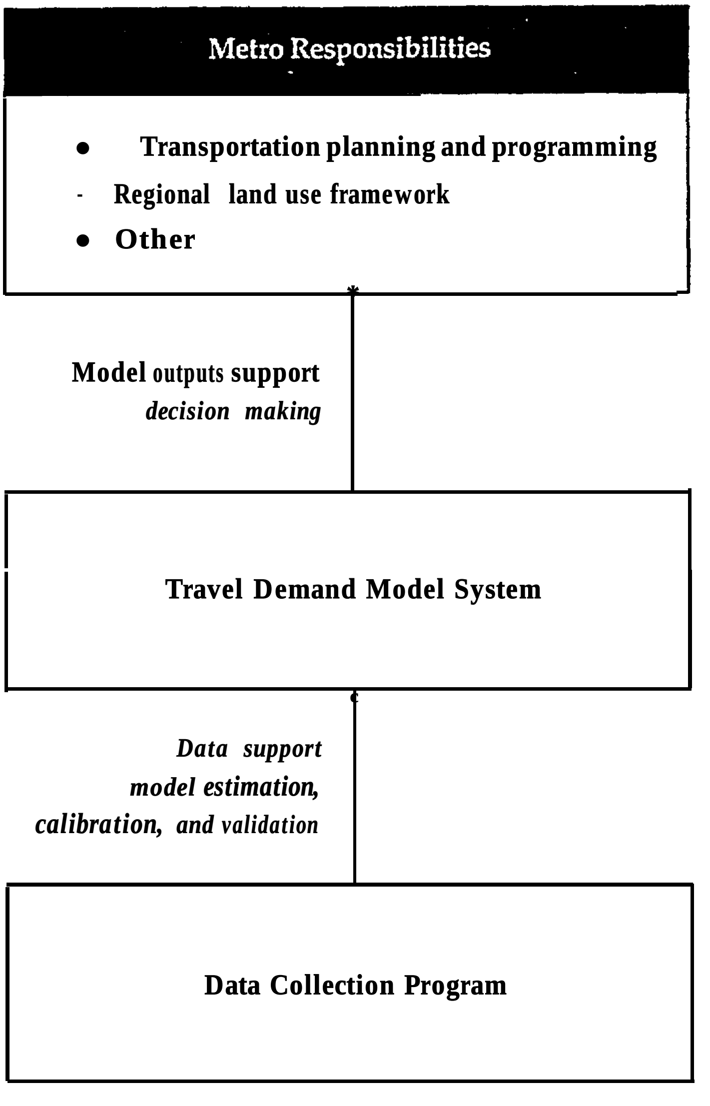
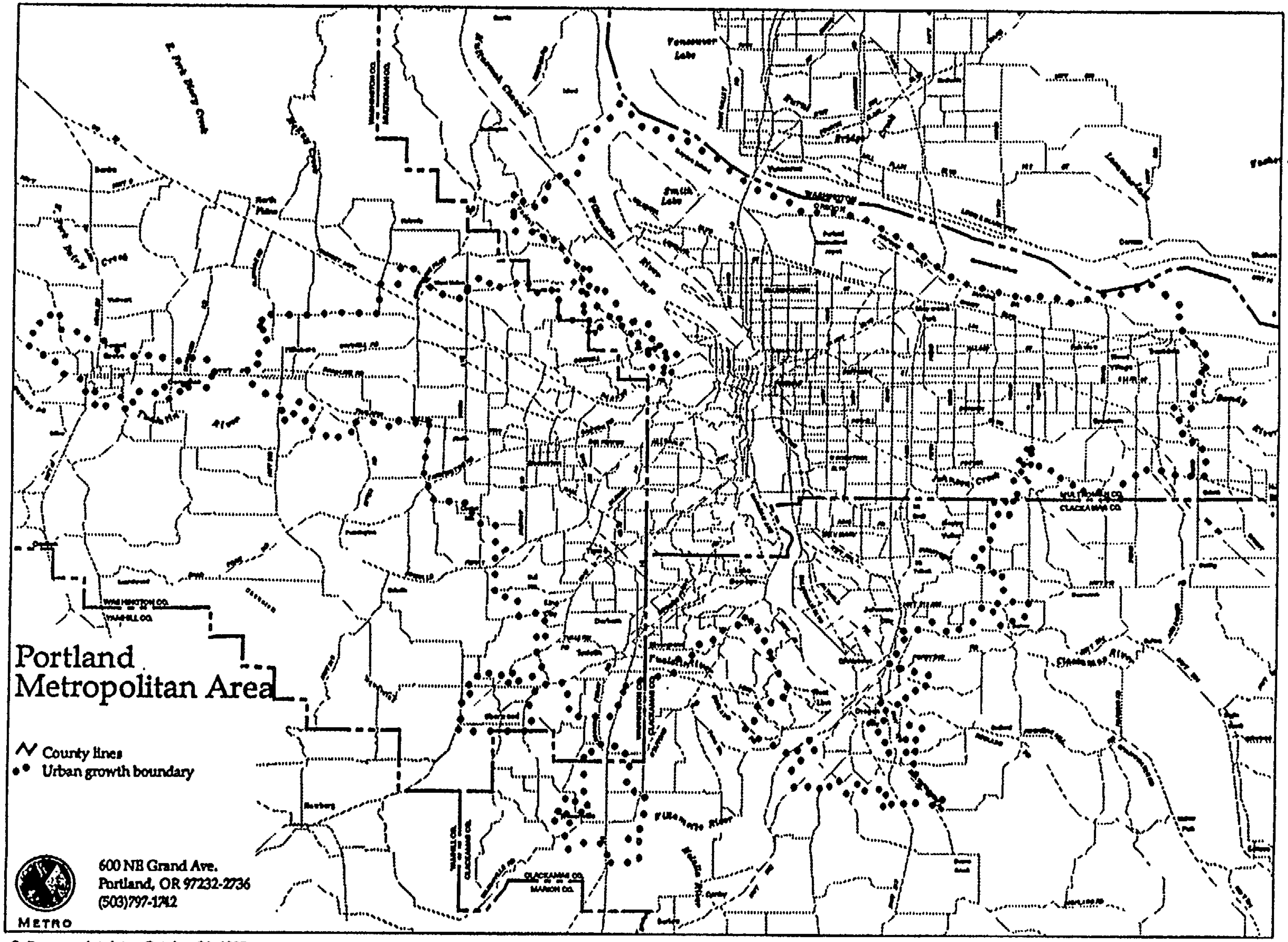


Figure 1.2 Portland Metro Area



S. Perone, plot date: October 24, 1995

Metro's responsibilities include preparation of the Regional Transportation Plan, the long range regional land use strategy, and the region's congestion management system. The agency is also responsible for establishing and maintaining the region's Urban Growth Boundary*, planning metropolitan area open spaces and parks, and planning transportation projects of a regional scope, including the Westside and South / North light rail transportation projects[2]. All local jurisdictions must be consistent with the regional framework established by Metro which encompasses land use policy, designation of current and future urban centers, and regional population and employment forecasts. Metro's authority was formally granted by voter referendum through a charter amendment in 1993.

Metro maintains a regional geographic information system (GIS) and a complete travel demand forecasting system to help carry out its regional land use and transportation planning responsibilities The travel demand model system and the GIS, known as the Regional Land Information System (RLIS) are also resources to local jurisdictions within the region. This case study focuses on data collected to support the travel demand model system. Because some of these data are stored and manipulated in RLIS, and since GIS is becoming increasingly integrated in the model system, certain aspects of the GE are described in the case study as well.

The key philosophy in Metro's approach to planning is that transportation and land use planning are inseparable, and that to effectively forecast future demands on the transportation system one must understand the environment which generates travel and influences travel needs.

– 1.3 Data Collection History

The set of transportation data required to support travel demand modeling in the Portland area, as elsewhere, have not been collected either at one time or as part of a single project. Rather, a multi-year data collection program has been used where multiple efforts are coordinated to produce the desired end product Important considerations in developing the overall data collection program have included data needs, data flexibility, costs, risks, timing, and resource availability.

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*According to the draft Regional Transportation Plan, the Urban Growth Boundary (UGB) is the politically defined boundary around a metropolitan area outside of which no urban improvements such as sewage treatment and water supply may occur. The UGB is intended to accommodate projected population and employment growth within a 20-year planning horizon.

[2] Metro's responsibilities also include solid waste management, operation of the Washington Park Zoo, and, through the Metro Exposition-Recreation Commission, management of the region's convention and spectator facilities.

The 1994 household survey builds upon a long history of data collection and model development in the Portland region. Since the early 1960s, Metro and its predecessor, the Columbia Regional Association of Governments (CRAG), have collected survey data and developed increasingly sophisticated transportation demand models. Major data collection and transportation modeling milestones at Metro are listed in Table 1.1. Metro's evolution from aggregate models and mainframe computers to disaggregate models and workstation/micro computing parallels that of transportation modeling at many MPOs across the country. Prior to the 1994 Household Activity and Travel Behavior survey, the most recent major household survey in the Portland region was conducted in 1985. Data from the 1985 survey form the basis for the generation of travel models currently in use.

1.4 Organization of Report

Chapter 2 of this report describes the Household Activity-and Travel Behavior Survey carried out in 1994-95, an example of data collection to address contemporary policy questions. Sections of Chapter 2 are referenced to relevant chapters and sections in the Travel Survey Manual[3] for readers wishing more background on topics such as sampling, survey design, and quality control. both the revealed preference and stated preference components of the survey are covered. Data collected in the 1994 survey will form the foundation for future model development and transportation planning activities at Metro.

Chapter 3 presents the overall data collection program that supports Metro's travel demand modeling activities. Sources of data include transportation supply data such as parking costs, system monitoring data such as traffic counts, and basic demographic, land use, and employment inputs. Information on the scope, content, cost, and use in travel demand forecasting are provided wherever possible. Metro will continue to collect these types of data to support of its future travel demand modeling activities. Chapter 3 also discusses the use of a number of different past surveys in estimating and updating Metro's current mode1 system. While the 1994 household survey will supersede past surveys as the source of model estimation data, the description of past practice is a good example of applying data from different sources to meet modeling needs.

Chapter 4 concludes the case study with an assessment of Metro's data collection program, recommendations to other agencies considering household survey efforts, and some general recommendations. A discussion of the applicability of the Portland experience elsewhere also is included.

3 **U.S. DOT, Federal Highway Administration,** ***Travel Survey Manual,*** prepared by Cambridge **Systematics, Inc., Cambridge, MA, April 1996.**

4.0 Recommendations and Conclusions

The data activities undertaken by Portland Metro illustrate one agency's approach to the collection and processing of land use, household, and transportation data that are desirable to support a contemporary transportation planning process. As increased emphasis is placed on multimodal considerations, intermodal connectivity, the efficient utilization of existing transportation infrastructure, and the interrelationships between transportation and land use; corresponding changes in the data used to support a travel demand model system also are appropriate. Data collected by a variety of local, regional, and state agencies can be assembled into a larger coordinated and comprehensive database. Information on individual activity patterns and preferences can be used to forecast consumer response to a broad base of policy and market-based measures.

Thisexamination of data collection at Portland Metro illustrates both the breadth and depth of information needed to support a modern travel demand forecasting system Data sources which support the model system range from traditional traffic counts and transit patronage to innovative stated preference data. A number of lessons and recommendations can be drawn from Portland Metro's data collection experience. Some of these pertain specifically to household surveys. Others relate to data collection in general.

■ 4.1 Household Travel Survey Recommendations

1. The structure of an existing model system should not necessarily dictate the design of data collection efforts. Metro recommends that jurisdictions acquire as much data as they can possibly afford and more than is currently required. In the same vein, maximum data should be obtained for the dollars expended. Metro's 1994 Household Activity and Travel Behavior Survey was designed to handle anything from traditional trip-based modeling to activity duration modeling. The flexibility and quality of the collected data are key. Of course, it is important to keep in mind that the ultimate measure of the success of Portland's household survey will be the quality of the travel models that are developed from the data.

2. In developing models from household survey data, the importance of exploring the data should not be overlooked. For instance, preliminary analysis of the 1994 data has revealed that accessibility is more important than parking cost in explaining trip chaining. This result emphasizes the need to avoid pre-conceived model structures and specifications and to not let existing models dictate data collection.

3. Training of the interviewing personnel is critical. Because surveys are becoming increasingly difficult to administer, polite and well-trained interviewers can make a significant difference in response rates. Also, it would be desirable to use survey personnel who are local or familiar with the area if possible. The survey firm that admhistered Metro's 1994 survey is based in Austin, Texas. Metro received negative feedback from survey respondents who were put off by the interviewers' lack of local **knowledge. For example, interviewers had to** ask for the location of the **Lloyd Center, a** popular shopping location, when retrieving activity data. This lack of local knowledge could conceivably contribute to lower participation rates or inaccurate data retrieval. Ultimately, however, it may be difficult in most areas to find interviewers who are both local and well trained in transportation surveys.

4. The exact wording of interview scripts and survey questions can have a significant effect on response and participation rates and should be refined with pretest results. Metro found that shorter interview introductions are preferable to longer ones. Also, the income question is quite sensitive. This question should be asked last to avoid abrupt termination of interviews.

5. Collecting flexible survey data does not necessarily cost much more than collecting limited data. Metro's cost per survey was in the range of $135 per completed household. Given that $100 per household is a typical cost for a one day survey and that Metro estimated about a 30 percent cost increase due to a two day format, Metro's costs were in line with experience in other areas.

- 4.2 General Recommendations

1. The use of GIS in the travel demand modeling process helps coordinate land use and transportation planning. Metro's travel demand modeling group obtains forecasts of household categories and employment from its own Data Resource Center. These forecasts are based on inventories of developable land stored in the GIS and consistent with regional land use policy. Strengthened links between the GIS and the travel demand model system will allow planners to reflect land use policy (changes in densities, etc.) with increasing accuracy and ease.

2. Careful planning of some types of household surveys can reduce or eliminate the need for other types of surveys. For example, Metro does not believe that a new transit on-board survey will be needed to estimate models using the 1994 household survey because that survey was designed to ensure a sufficient sample of transit trips.

3. Inter-agency coordination can greatly enhance the quality and quantity of data available in a given region. For example, Tri-Met commissioned a stated preference survey on transit-related subjects as part of the overall 1994 survey effort. Also, the 1994 household survey was administered simultaneously in several MPOs This arrangement resulted in economies of scale while allowing different jurisdictions and agencies to pay for customized data. At the same time, Metro's efforts to coordinate

collection of traffic count data point out the difficulties of inter-agency coordination. Nonetheless, there is much to be gained from improved inter-agency coordination in data collection in most regions.

4. Plans for major new data collection efforts should be carefully thought through so as not to waste what may be a rare opportunity since survey administration is becoming increasingly difficult due to privacy and security concerns. Metro staff members feel that it would not be feasible to repeat a survey similar to the 1994 Household Activity and Travel Behavior Survey in the next few years.

5. Results from major data collection efforts can be updated with smaller, focused supplemental surveys. This principal was illustrated by Metro's use of the 1988 "After-MAX" Household Survey to update the travel models estimated from 1985 household survey data.

■ 4.3 Conclusions

The Portland area provides an example of a successful data collection program for transportation planning and travel demand modeling. The program is designed to provide the specific data needed for the planning and modeling efforts and provides a level of detail that is not often found in U.S. urban areas. While. as this report is being prepared travel demand models have not yet been developed from the 1994 survey data, the earlier data collection efforts, which focused around the 1985 household survey, produced a travel model system often cited as one of the most innovative in the U.S.

Besides the high quality household survey efforts, another feature of the Portland area data collection program that stands out is the level of effort devoted to, and the corresponding high quality outputs of, the demographic and land use data development process. In particular, the use of GIS has produced detailed data that are more precise than commonly available in U.S. urban areas.

When assessing the transferability of Portland Metro experience, it is important to recognize the region's special characteristics. First, the region served by Portland Metro is a relatively small and highly cohesive metropolitan area. The success of the 1994 survey may be partly attributed to this factor. Second, the Portland area is viewed by many to be a relatively progressive area. As such, it may be easier to obtain cooperation from individuals for participation in what can be perceived as time-consuming and intrusive survey research efforts. Finally, Metro is one of the few Metropolitan Planning Organizations with the legal mandate and resources to put the philosophy of integrated land use and transportation planning into practice. This situation contributes to the impressive array of geographic data collected by Metro and the advanced use of environmental factors in its models. This effort is made possible by the high level of resources devoted by Metro to these activities.

Other jurisdictions clearly can benefit from the Metro experience in a number of ways. GE technology is becoming more affordable and accessible and can provide a spatial framework for organizing related land use, demographic, employment, and transportation data. Improved cooperation among different agencies and jurisdictions in regions can enhance the quality and quantity of transportation data. Finally, very careful planning of data collection programs, in particular major household survey efforts will conserve scarce data collection resources and ensure that the data can meet a variety of needs.

There are a few cautionary points that should be made when considering the applicability of Portland's data collection program to other areas. The first is the issue of resources. Many areas have fewer available staff and financial resources available for detailed data analysis, especially in the areas of household travel surveys and GIS. While consultants could, to some extent, help with the issue of staff expertise, the budget issue must be dealt with by every agency. A second issue is that some data collection efforts, especially the household survey, can place a heavy burden on respondents in terms of both time commitment and willingness to reveal what some might consider private information. Not only might potential respondents in some areas be less willing to make the necessary commitment, but the political will needed to oversee such efforts might not exist. This may be particularly true in areas where decision makers are not familiar with transportation planning and modeling needs.

In summary, answers to today's policy questions require the breadth and depth of data collected by Metro. While some jurisdictions may not be able to perform all aspects of Portland's program at the same level, Metro's program of data collection and transportation modeling offers much to be emulated.

TRAVEL TIME DATA NEEDS, APPLICATIONS, AND DATA COLLECTION

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Travel Time Data Needs, Applications, and Data Collection

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OVERVIEW

Travel time or speed is considered the most effective measure for transportation system performance. It is a key data element in almost all types of travel models and a sensitive decision-making variable that transcends the value of travel behavior and the impacts of traffic conditions. The use of travel time or speed measurements is applied in many phases of multi-modal transportation planning and decision making, whether it is for long-range forecasting and investment decisions, or short-range evaluation of traffic operations or travel demand strategies. It is a measure that needs to be established and used for integrated transportation planning **and** air quality analysis called for by the Inter-modal Surface Transportation Efficiency Act (ISTEA) and the Clean Air Act Amendments (CAAA).

Travel time is also an effective measure for congestion. Congestion occurs when travel demand (or flow rate) exceeds system capacity. Congestion is often formed in expeditious and exponential fashions resulting in delays, fuel consumption, and air pollution. To measure congestion and congestion-induced effects correctly, the spacial and temporal distribution of travel time and speed measurements ought to be examined more thoroughly and systematically by location and time span. The duration and magnitude of congestion can then be measured to determine the level of congestion across roadways and time periods (peak vs. off-peak) or the system as a whole. With systematic route coverage and data collection by time period, congestion can be measured as:

- Average speed - miles per hour (peak vs. off-peak) by route segment;
- Delay - difference of travel time (or minutes per mile) in excess of normal (or off-peak) travel time;
- Duration - length of time average travel time exceeds normal travel time (off-peak);
- Spread - number or percent of route miles or VMT (vehicle miles traveled) with delay; and
- Intensity - ratio of peak to off-peak travel time.

Since level of congestion is a key factor in impact assessment and in the evaluation of alternative transportation strategies for congestion reduction and mobility improvements, it is important to collect and use travel time on a consistent and continuous basis for congestion monitoring and development of congestion measurements. Level of congestion is also an important factor in determining sample size required for data analysis and data establishment for transportation planning and decision making.

In practice, travel time data has only been collected sporadically in US cities, as revealed in a 1991 survey by the Federal Highway Administration (FHWA). Insufficient sample size resulting from limited floating car runs or random sources failed to provide a valid database for capturing the variability of travel time and level of congestion. The data are often not collected in a consistent manner which would allow meaningful trend analysis or intercity comparisons.

These findings prompted the FHWA to initiate a field test of travel time data collection. During the summer and fall of 1993, a series of travel time surveys were conducted in Boston, Massachusetts, Seattle, Washington, and Lexington, Kentucky. A range of six data collection techniques were tested across 15 major freeways and principal arterial streets on multiple days and route segments. The methodologies tested were:

- License plate matching with video;
- License plate matching with portable computer;
- Floating car;
- Probe vehicle;
- Automatic vehicle identification (AVI) bus; and
- Loop detector.

While the evaluation of data collection methodologies focused on the strengths and weaknesses with respect to particular facility types and roadway settings, lessons learned also included the costs and effectiveness of the methodologies in terms of sample rate and sampling efficiency.[1] Other more general conclusions emphasized the need for standardized data processing, analysis, and report production, as well as the establishment of standard data formats and data collection procedures.

The travel time study concluded that there is no single best methodology across all roadway types and traffic conditions. Selection of appropriate technique(s) for travel tune data collection depends largely on the required sample size for an analysis application and the sampling efficiency of the methodology. Sampling efficiency could be measured as costs per unit of minimum (or optimal) sample size required. Since the minimum sample size required depends on the level of analysis and its application, selection of methodologies for travel time data collection, or the overall effectiveness of a travel time data collection program for multiple applications, should include the following considerations in establishing data collection plans and selecting data collection methodologies:

- Level of analysis (area wide, corridor, site);
- Type of facility (freeway, arterial, collector);
- Scope and Coverage (# routes, # locations, # lanes, # intersections);

- Duration of time (# days, # hours, daily, peak/off-peak, 15-minute time slice);
- Level of congestion (duration, spread, intensity);
- Single or multiple applications (CMS, project evaluation, or model development); and
- Budget and staff constraints (full time, temporary staff, contractors).

As financial constraints and scarce resources are increasing concerns in public investments, the efficiency and effectiveness of data collection and the use of the information become more critical to the planning and decision making process. This paper presents an overview and discussion of travel time data needs, applications and the effectiveness of data collection. Coupled with the "Travel Time Data Collection Field Tests - Lessons Learned" document, state or metropolitan planning organization (MPO) officials can use the information to identify their own data needs and priorities in travel time data collection, as well as design and conduct travel time surveys using the selected techniques.

TRAVEL TIME DATA NEEDS AND APPLICATIONS

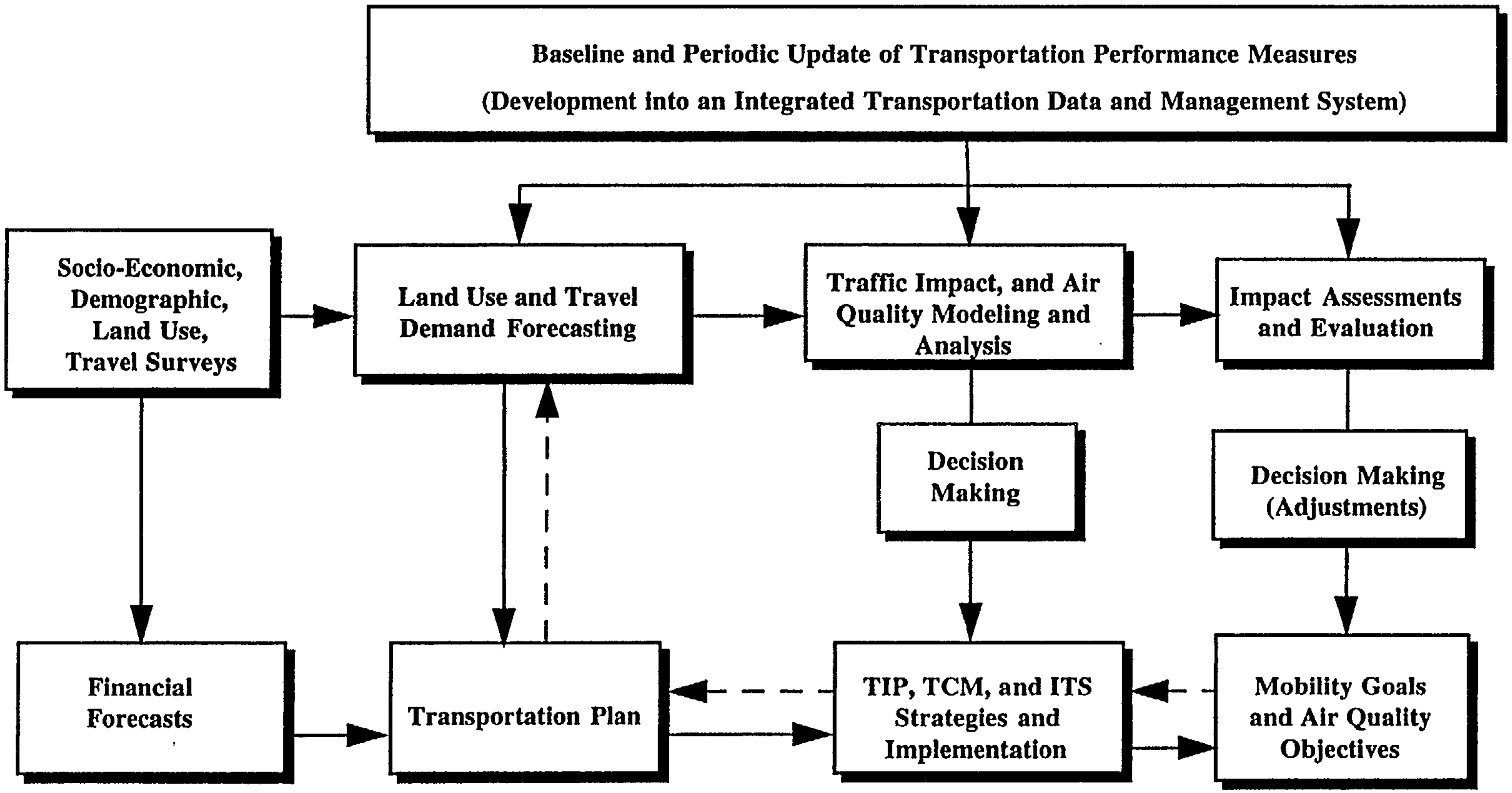
As a performance measure and a decision making variable, travel time or speed data are useful in many aspects of transportation planning, modeling, and decision making applications. These applications include: traffic and performance monitoring, congestion management, travel demand modeling and forecasting, traffic simulation, air quality analysis, evaluation of travel demand or traffic operations strategies. The data are required at different levels and many of these applications depend on estimated or predicted values rather than field observations. The quality of data is critical to the effectiveness of the planning and decision making process including model development and application.

The data required for an analysis or evaluation depends on the type of application and decision making, the scale of spacial and temporal distribution, and level of detail. Figure 1 describes the planning and decision making process including three categories of data: 1) traffic data and system performance measures; 2) planning data: socioeconomic, land use, and travel characteristics; and 3) financial data. The discussion which follows focuses on travel time as a key data element in the planning and decision making process. The data need to be established in a consistent and continuous manner to satisfy the planning data requirements.

Transportation Planning and Decision Making

Under ISTEA, an urbanized area with a population over 200,000 is required to prepare a metropolitan transportation plan (MTP) The MTP, along with the state transportation plan (STP), has a time frame of 20 years, and should have long term vision of land use, economic development, urban growth, transportation investments, congestion, and the environment. In conjunction with the CAAA requirements, the MTP should set forth measurable guidelines and procedures in the state implementation plan (SIP) for selecting and monitoring transportation improvement programs (TIP) in order to conform with the air quality objectives required in

Figure 1. Transportation Planning and Decision Making Process



non-attainment areas. Transportation Improvement Program (TIP) is developed on a short-term basis (3-5 years) and must serve as the programming mechanism for focusing and prioritizing projects, allocating resources, and establishing relationships among projects in order to achieve mobility goals and air quality standards[2]

The ISTEA and CAAA emphasize integrated planning and balancing between economic development, land use, transportation, and the environment. In this planning process, more adequate data and performance measurements need to be established as a benchmark for identifying deficiencies and future needs in support of decision-making and program development. Land use and transportation modeling and forecasting are required for long-range planning. In the 20 year planning horizon, the baseline performance measures are established and need to be updated periodically allowing needed adjustments or correction to the selected and implemented transportation improvement programs.

The TIP is financially constrained, and should be effective and realistic with regard to resource allocation. The range of TIP's include not only capacity improvements or system operations, but also a range of travel demand management (TDM) or pricing strategies that could be more cost-effective options. Reliable travel time measurement would be very effective in promoting or evaluating such strategies. For example, for an high occupancy vehicle (HOV) lane proposed in a congested corridor, only a significant travel time reduction via revealed data measurements would impact motorists' decisions to divert from single occupancy vehicle (SOV) operation. Congestion pricing is another viable option in curbing severe urban congestion. To quantify and evaluate the profound impacts in travel behavior and/or aggregate system effects of these options, it is most effective to collect and use the information in terms of the user benefit in saved travel time.

Assessments of economic and environmental impacts, and evaluation of the cost-effectiveness of alternative transportation control measures (TCM) rely on solid baseline information through comparative analyses using: travel behavioral or travel demand modeling, sensitivity analysis, pricing elasticity, or traffic simulations. Travel time/speed is a predominant behavioral and decision-making variable, as well as a performance measure in these analyses. The consistently and continuously established performance measurements provide a foundation in the planning process and the data are used for problem and needs identification, analysis and modeling, project evaluation, and decision making.

Level of Analysis

For planning and decision making purposes, transportation projects and investments are usually categorized in three levels of analysis:

- Metropolitan area (land use, urban growth, travel demand, and air quality planning)
- Corridor/subarea (traffic and congestion monitoring, and ISTEA intermodal planning)
- Site (activity, traffic, and impact analysis)

All three levels of analysis require data of good quality. The level of detail and precision required for decision making may vary depending on the type of application. For example, more detailed data is required for arterial design or system operations while consistency and regularity are emphasized for corridor planning or traffic monitoring. The level of data required depend on roadway type, traffic patterns, congestion level, and type of analysis. For congestion measurements, sample size is determined by the variability of travel time and level of congestion.

Data collection is expensive and time consuming, this is especially true for comprehensive and area wide data collection. Regional or metropolitan level planning data requirements are difficult to attain for large urban areas. O-D trip table/travel time data are often obsolete or poorly updated by the states or MPOs Daily average volume or travel time data collected from limited random samples is meaningless on highly congested corridors for either planning or modeling applications. For small to medium size urbanized areas (population 200,000 to 500,000) with steady growth and new development, a comprehensive, area-wide data collection and modeling process is more manageable.

For large urban areas, travel time data collection and performance measurement is best defined and established at the corridor level. Resource allocation and data collection can be determined based on priorities set by the measured problems and needs, level of congestion, and air pollution. Route and segment specific travel time measurements can be collected to capture traffic or travel characteristics by facility type, location, and time of day.

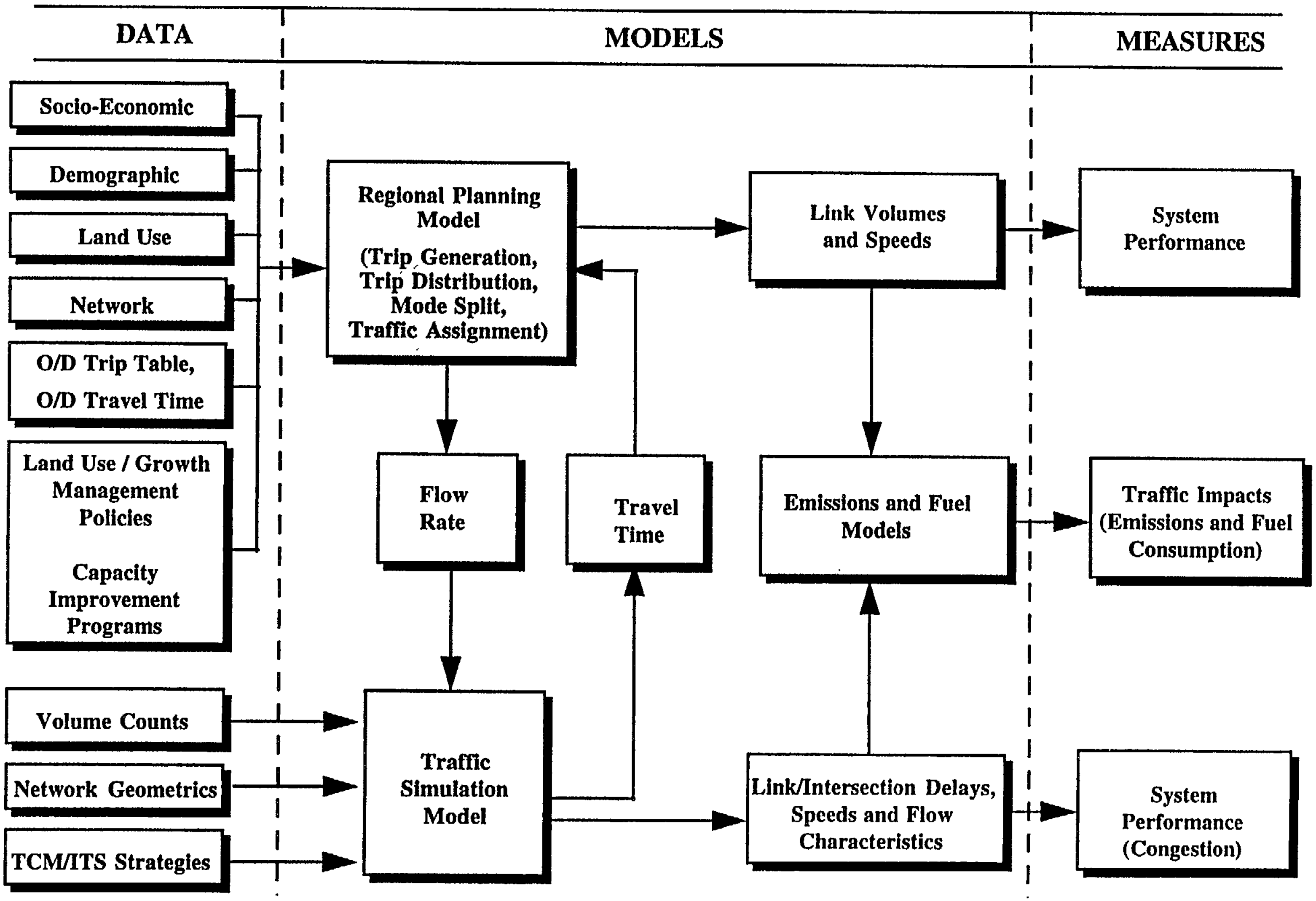
Site impact analysis is confined to specific locations and requires more detailed micro-level analysis. The data required and data collection usually rely on on-site surveys or interviews. The analyses focus on activities, space and densities, public transportation, and parking facilities. Urban design and site planning are emphasized including pedestrian, bicycle, or ferry facility design as vehicle trip reduction measures. Employer based trip reduction ordinances, flexible working hours, and parking policies are TCM's considered at large urban activity centers.

Travel Demand, Traffic, and Impact Models

The analysis of travel demand and transportation supply relies a great deal on models as well as good data. Models are developed and used for long-range forecasting, simulation, design, and evaluation. The structure or type of models (demand or supply) reflects the level of analysis. The types of modeling applications include: land use and transportation forecasting, travel demand and behavioral analysis, 'discrete or multinormial choice (mode, destination, route choice), traffic assignment and simulation, capacity design, signal design and flow optimization, traffic impact assessment, emission, fuel, and air quality modeling.

Travel time or speed measurement is an essential and sensitive decision-making variable in almost all types and all levels of transportation models. Figure 2 describes an integrated transportation modeling framework. Travel time or speed is identified as an input/output, and a decision making

Figure 2. Travel Time and Speed in Integrated Transportation Models



or analysis variable at various levels for both long-range planning or short-term traffic and impact analysis.

In the conventional 4-step transportation planning models, the use of travel time or speed measurement ranges from an impedance in spatial interaction and allocation, to utility characterization in trip destination, mode choice, and route choice decisions. The input data for trip generation and distribution steps include socioeconomic, demographic, and land use data, as well as growth management and transportation plans and policies. Mode split is typically determined by mode shares and a diversion factor in which travel time and transit fares are the most sensitive variables for shifting demand.

Link volumes and travel speeds are predicted on a network with any number of iterations and the results are subject to reality checks in the baseline model calibration. In state-of-the-art traffic models, speeds and delay (due to congestion) are projected at links and intersections based on more realistic and dynamic flow rates and more detailed network descriptions. This type of network based modeling has promised to be more appropriate for evaluating traffic control and management strategies such as adaptive signal optimization, ramp metering, or ITS related strategies (e.g., route guidance, variable message signs, and electronic toll collection, etc.) but also requires more intensive data.

For emission, and air quality modeling and analysis, the current practice relies on the outputs of models. Because of the lack of field measurements for traffic data, the outputs of transportation planning or traffic models, become the main data source and input for estimating vehicle emissions and fuel consumption. The key variables for the EPA mobile source models include:

- VMT estimates by eight vehicle classes;
- Total number of vehicle trips and trip length distributions;
- VMT by speed class (by roadway functional class); and
- VMT by time of day (characterized by average speeds for the time period) by functional class.

Average speed and VMT by vehicle class are two key variables in EPA mobile source models for estimating total emission outputs. The emission rates are applied to respective traffic parameters to calculate group and total emission estimates. The level of analysis may seem coarse but still requires data analysis and modeling process at various disaggregate levels. More accurate and detailed speed measurements (e.g., U-minute speed cycles) would be useful for measuring site or link level congestion effects.

As the need for improved and integrated transportation and air quality planning grows, the process for integrated travel demand, traffic, and impact modeling also needs to be improved. Improved and systematically established travel time data could enhance model development and performance through accurate baseline data for model calibration and validation.

TRAVEL TIME MEASUREMENTS

Travel time can be simply described as the amount of time required to move people (or goods) from one place to another (by way of a transport). For ground transportation, the measurement is taken as the average of vehicle times or speeds over a given distance during a period of time. In highway design and traffic analysis, it is necessary to take into account the vehicle type, the path or roadway type, and the flow conditions. In the Highway Capacity Manual (HCM), travel time is defined as the amount of time of vehicles traversing a route or route segment. Average speed is computed by taking the length of the highway or street segment under consideration and dividing it by the average travel time of that segment. Roadway type in HCM is classified into eight functional classes. Flow condition is generally characterized by traffic density, or volume-to-capacity (V/C) ratio. V/C is also classified into six (A-F) levels of service (LOS), which represent conditions ranging from free flow, degree of headway spacing, to heavy congestion.

The dynamics of traffic flows can be illustrated by a travel time or speed curve. The speed variation is usually captured by the peak and off-peak speed average. However, the scope and extent of speed variation in terms of spacial and temporal distribution of travel times may be represented more appropriately by travel time (speed x distance) or delay to show the effect of congestion.

In highway design and traffic engineering, the speed and volume relationships are analyzed for each highway segment which has uniform traffic and control conditions. Since the scope and range of speed variation can shift dramatically during congestion periods, it is best measured at 15 minute intervals (a time slice usually considered a reasonable interval during which stable flow exists). As travel time is not as easily measured from a fixed location as volume counts, it is more often estimated from a speed formula or a network model. Speed is calculated as a function of facility type, roadway geometries, vehicle volume, and density. When only volume and capacity data are available, LOS is used as the common variable to indicate performance or congestion. Average speed drops abruptly from the free flow speed when traffic density increases (LOS $\geq$E) and sustains through an extended period.

To measure and use travel time for various applications, travel time is usually measured and described as the following types:

- Origin-Destination (O-D) Travel Time;
- Route Segment Travel Time or Average Speed;
- Link Time or Speed;
- Spot Speed;
- Intersection Delay; and
- Excess Delay.

O-D Travel Time

O-D or zone-to-zone travel time is captured in regional transportation planning models. O-D distance and travel time are usually obtained via floating car samples or household travel surveys. As an O-D pair may include several roadway segments and facility types, the access and egress time, and running time for transit or an alternative mode, it **is** a composite measure used mainly for sketch planning.

Route Segment Travel Time

Route segment travel time is considered the most appropriate level for traffic monitoring, congestion management, and corridor planning.[3] A route can be selected from any roadway type for data collection and can be defined as: downtown CBD to suburban center, suburban to suburban centers, CBD to airport, or a beltway. Route segment is defined as a section of the route with uniform traffic and operating conditions. Travel time, speed, and any other traffic parameters (volume, vehicle class, and occupancy), as well as congestion measures, can be established at the route level. This data could be established consistently with the Highway Performance Monitoring System (HPMS) or the National Highway System (NHS).

Link Travel Time

A link is defined as the space between any two adjacent nodes on a transportation network. A node is typically an intersection, freeway interchange, terminal facility, or zone centroid. A network model predicts the volume and speed at the link level. For a detailed network and microscopic traffic simulation model, the link as well as intersection characteristics are described in much greater detail. The intensive labor effort required for data collection and validation confines analysis to a relatively small scale and time duration.

Spot Speed

Spot speeds are measured at fixed locations via traffic detectors or video surveillance systems. Vehicle speed can be calculated from the time the vehicle takes to pass between two loops set apart at a known distance. This measurement gives the point or time mean speed at a given location. Spot speed can be a good indicator or surrogate for congestion measure. While there are many types of sensors/detectors which produce spot speed as a traffic parameter, the reliability, precision, and potentials for planning applications need further development and testing.

Intersection Delay

Queue delay at intersections is caused by signal timing, turning movements, and mostly traffic flow density, The extent of delays and traffic-patterns from all directions are inputs for adaptive signal timing plans or intersection design. Certain roadway facilities can absorb more vehicle stops than others without causing extended delays and bottlenecks.

Excess Delay

Excess delay is measured as the excess travel time in comparison with free flow or an acceptable travel time for a traffic condition. The amount of delay can be measured as minutes per mile. At the aggregate level delay can be an effective economic and congestion measure for setting up pricing or parking policies.

TRAVEL TIME DATA COLLECTION

Data Collection Practice

Travel time data has only been collected sporadically and inconsistently among US cities, as revealed in the 1991 FHWA survey. Journey time, average link speed, and delay data are collected for corridor or regional travel time studies. Other studies collecting travel time data include major routes connecting activity centers to CBD, highway and transit access to regional airports, and HOV lane operations. Few studies were cited as collecting travel time for model improvement. Floating car was quoted as the most commonly used method for collecting travel time data.

Although some regional studies included up to 20 corridors and hundreds of miles route coverage, there is no emphasis on travel time variability. Most measurements are based on limited floating car samples. None of the surveyed studies could have provided a statistically valid database to display the range of travel time distribution and variability needed for congestion management.

In a 1992 survey on the state of the practice on congestion and mobility measure&, 12% out of 92 responding state DOT's or MPOs indicated using travel time or speed (19% also used delay) as a congestion or mobility measure, while 90% of the respondents used LOS. In a question where respondents were asked to suggest measures, 24% suggested the use of travel time/speed, 3 1% delay, and only 9% to use LOS. The most commonly cited reason for not being able to use travel time, speed, or delay as a congestion measure was inadequate staffing and budget.

Data deficiency has been a common problem and a challenge in planning practice. Although travel time may be a preferred measure for quantifying congestion, there is always a gap between the existing data establishment and ideal or standard data requirements. In planning applications, the data is not always available or in the right form as needed. Data collection efforts are rarely included in project plans or considered during development as a high priority activity. Data collection often relies on existing data establishments. It is common that an analysis or project evaluation is conducted on the basis of whatever data is available rather than what is needed. Frequently, data used for an analysis or model application are based on out-of-date or limited data sources.

The ineffective or insufficient planning data establishment and the lack of integration with modeling applications has often been criticized as a weakness in planning practice. In comparison with traffic data establishment, the HPMS is regarded as a useful and perhaps the most consistent national database of highway characteristics and traffic information. Although traffic data (volume counts, vehicle mix, occupancy) collected in the HPMS are mainly for interstate and major highway segments, some states and MPOs have chosen to expand their own database to include data collected on uncovered roads. Route and segment travel time data are currently not required as part of the HPMS. A standardized travel time data program could enhance the HPMS for traffic and congestion monitoring, as well as for trend and intercity comparison.

Data Collection Methodologies and Techniques

There are many different methods and techniques for travel time data collection. Floating car, aerial photography, or radar have been traditionally used to capture average flow speeds and traffic density. Household travel surveys are performed to obtain samples of O-D travel time and mode selection. Spot speeds can be obtained along with volume and lane occupancy data via loop detectors or video surveillance systems. License plate matching is also used to track vehicle at various observation locations thus capturing the elapsed times across roadway segments.

More advanced techniques capable of collecting travel time measurements include: automatic vehicle identification (AVI), automatic vehicle location (AVL) via a geographic positioning system (GPS), or probe vehicle via cellular phone or in-vehicle device delivering traffic and travel information to a traffic management center. With the advance of computer, electronics, and communication technologies applied in intelligent transportation system (ITS) infrastructure and deployment, travel time data collection and information processing will or could eventually be performed on the real time basis.

In general, the various data collection techniques can be characterized as floating car versus license plate (or ID) matching. Floating car, test vehicle, or probe are similar to each other in that information on the entire vehicle trip can be selected and collected. License plate matching involves data collection at pre-selected locations where link or segment travel times are calculated from matched license plates or AVI. Data capturing, processing, and reporting involve a series of machine or manual steps and processes. Successful ability to collect a valid sample rate depends on operator's experience and skills and the machine recognition performance and processing. Advanced techniques (e.g., AVI) increase data accuracy, capturing almost 100% of the fleet size, but are infrastructure or location dependent.

Table 1 is a summary of the six methodologies tested for travel time data collection. More detailed descriptions of the methodologies and step-by-step survey procedures, data processing, and analysis are described in the study report "Travel Time Data Collection Field Tests - Lessons Learned". A comparison of the advantages and disadvantages of methodologies by operational characteristics, sample rate, and the effectiveness of data use is provided in Appendix A.

Table 1. Comparison of TraveI Tie Data Collection Methodologies

Methodology	Measurement Type	Infrastructure Dependent	Roadway Type		Sample Rate	Measure of Congestion
			Arterial	Freeway		
Floating Car	LiiOD	No	X	X	LOW	**Fair**
Probe	Link/OD	No	X	X	**Med.**	Fair
License Plate Mat. - Video	**Link**	No	X	X	High	Good
License Plate Mat. - Computer	***L i i***	***No***	***X***	***I***	Med.	Good
AVI	Link/Spot	Yes	X	X	Fleet Size	**Good**
Loop	spot	Yes	X	X	N/A	Good/Fair

Selection of Methodologies

In selecting methodologies, there is no simple answer. No one methodology is suited for all types of roadway and traffic conditions. One recommendation, currently implemented in Boston, is the use of floating car to collect baseline travel time information, complimented with a more rigorous approach when increased sample size and level of detail is needed.' As sample size required and sample efficiency are key factors in methodology selection, it is important for the performing MPOs to determine their data needs and the scope and priorities of data collection before selecting methodologies for data collection. The minimum sample size required for a particular roadway should be decided by its unique traffic and congestion pattern, and the type of analysis required.

Appendix B lists transportation programs and activities requiring travel time data at three analysis levels (area, corridor, and site) for decision making. The measurement type and level of derail required are mapped with applicable data collection methods. Multiple methodology choices are available for each application, however, the final selection of methodology depends on factors such as the duration and extent of peak traffic conditions, route coverage, and sample size required for the analysis. Table 2 shows the parameters that need to be considered in establishing comprehensive travel time data collection plans before selecting appropriate methodologies.

Table 2. Parameters in TraveI Time Data Collection Planning

Consideration	Parameter
Level of Analysis	area wide, corridor, site.
Scope and Coverage	route selection, priority, # routes, # route miles, # sites, # lanes.
Type of Facility	freeway, arterial, collector.
Duration of Time	# days, # hours, peak hour duration, 15-minute time period.
Level of Congestion	duration, spread, intensity.
Sample Size	# observations per hour, # observations per 15-minute, % volume.
Update Cycle	data update cycle, sample level.
Methodology	floating car, license plate matching, AVI, detector, video camera.
Data Processing	route, segment, or system level; daily, peak, off-peak, direction, average speed, travel time, delay, total vehicle hours traveled.
Budget and Staff	full time or temporary staff, contractors.

CONCLUSIONS: NEED FOR TRAVEL TIME DATA ESTABLISHMENT

The collection and establishment of travel time based performance measures is most effective for traffic and congestion monitoring at the corridor or system level. Periodically updated performance measures could be used for before-and-after comparison, trend analysis, and evaluation of the effectiveness of implemented TCM strategies for congestion reduction or air quality conformity requirements. As illustrated in Figure 1, an integrated transportation data and management system could be developed as the foundation for enhanced intermodal and air quality planning and decision making. The effectiveness of the planning process depends on well connected and well established data. The information developed should be clear and easy-to-understand by the public and decision makers as congestion, mobility, and air quality will continue to be economic, social, and political priorities.

Consistent and continuous data collection for coordinated and comprehensive planning applications and decision making (CCCC) could satisfy the need for data collection and data establishment driven by the ISTEA and CAAA requirements. Among the planning and traffic data needs, travel time has been identified as an essential data element but a weak link in the existing data establishments. As travel time, speed, or delay measurements capture the essence of mobility, efficiency, as well as environmental consequences, the improved travel time data collection and data establishment could greatly improve the process and effectiveness of transportation planning and decision making applications.

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Appendix A. Comparison of Travel Time Data Collection Methods

Method		Operational Characteristics							Sample Rate				Effectiveness				
		Measurement Type	Infrastructure Dependent	Observation Locations	Equipment Intensive	Labor Intensive	Technology Readiness	Training/Special Skills	% Volume Captured	Matches Per Segment Per Hour	Sample Efficiency	Data Accuracy	Route Type	Lane Discrimination	Captures Traffic Dynamics	Measure of Congestion	Other Traffic Data
License Plate Matching	Video	Link[1]	No	Fixed	Yes	No	Dev[3]	High	Highway 10-40%	160-400	Increases with Machine Recognition Rate	High	Highway Arterial	Yes	Yes	Good	Volume, Vehicle Mix, Headway, Occupancy, Density
License Plate Matching	Portable Computer	Link	No	Fixed	Yes	No	Yes	Low[5]	Arterial 60%	100-200	Decreases as Traffic Speed Increases	Med[7]	Arterial	Yes	Yes	Good	-
Floating Car		Link O/D	No	Flexible	No	Yes[2]	Yes	Med	3-4 Runs / Peak Period	N/A	Decreases as Congestion Increases[6]	Med[8]	Highway Arterial	No	No[8]	Fair	Delays. Incidents
Probe Vehicle		Link O/D	No	Flexible	No	Yes	Dev.	High	Probe Fleet Size	N/A	Decreases as Congestion Increases[6]	Low	Highway Arterial	No	No	Fair	Delays. Incidents
AVI		Link Spot	Yes	Fixed	Yes	No	Dev.	Low	Equipped Fleet Size	N/A	90%	High	Highway Arterial	No	No	Good	-
Loop Detector		Spot	Yes	Fixed	No	No	Yes[4]	Low	Total Volume	N/A	~100%	Med[4]	Highway Arterial	N/A	Yes	Good/ Fair	Volume, Occupancy

[1] Link - Link or route segment

[2] Per Sample required

[3] Dev. = developmental

[4] Volume/speed relationship needs development

[5] Results vary significantly by individual ability

[6] As congestion level increases:
- Minimum sample size required significantly increases
- Run Length and number of cars required increases

[7] Caused by partial plate matching

[8] Can be affected by driver behavior and sample deficiency

Appendix B. Mapping Travel Time Data Collection Methodologies With Analysis and Decision Making

Level of Analysis / Decision Making	Measurement Type					Level of Detail				Data Collection Methodology						
	O/D	Link/ Route	Inter- section	Spot	Delay	15 Minute	Peak	Off-Peak	Daily	Floating Car	Probe	License Plate Matching: Video	License Plate Matching: PC	AVI	Loop	Survey
Area Wide																
Isochronal Chart		X					X	X		X	X	X	X			X
Land Use / Transportation Forecasting	X	X					X	X	X	X	X	X	X			X
Growth Management	X	X					X	X	X	X	X	X	X			X
Air Quality Conformity Analysis	X	X	X		X		X	X		X	X	X	X			
Corridor																
Roadway Design		X	X				X	X		X	X	X	X			
Capacity Improvement		X	X		X		X	X		X	X	X	X		X	
Signal Optimization		X	X		X	X	X	X		X	X	X	X		X	
Ramp Metering		X		X	X	X	X	X				X	X		X	
Traffic Monitoring		X			X	X	X	X				X		X	X	
TDM Strategies																
HOV / Rideshare		X			X		X	X		X	X	X	X	X		X
Transit		X			X		X	X		X	X	X	X	X		X
Flexible Work Hours	X	X			X		X	X		X	X	X	X	X		X
Telecommuting	X	X					X	X		X	X	X	X	X		X
Congestion Pricing		X			X		X	X								X
ITS																
Electronic Toll Collection (ETC)		X			X	X						X		X		
Incident Management		X			X	X						X			X	
ATMS/ATIS	X	X			X	X	X	X			X	X		X	X	
Air Quality Analysis		X	X		X	X	X	X		X	X	X	X	X	X	
Site																
Employer Trip Reduction Ordinances		X			X		X	X			X					X
Parking Restrictions		X			X		X	X			X	X	X			X
Impacts Assessment		X			X		X	X				X	X			X
Air Quality Analysis		X	X	X	X	X	X	X		X	X					

GLOBAL POSITIONING SYSTEMS FOR PERSONAL TRAVEL SURVEYS

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GLOBAL POSITIONING SYSTEMS FOR PERSONAL TRAVEL SURVEYS

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ABSTRACT

Personal travel and how it changes is of continuing concern to transportation planners and policy makers. Information abbut daily travel patterns and trip purposes, time of day decisions, mode choice decisions, and trip chaining decisions are generally captured using self-reported information using a written diary and telephone retrieval. This project developed a small, user-friendly, mailable unit including a Global Positioning System (GPS) element that does not need a trained technician for installation in a private vehicle. The unit was developed to capture variables that would be entered by the vehicle driver using a menu, such as trip purpose and vehicle occupancy, and to capture automatically-recorded variables such as date, start time, end time, and latitude and longitude at frequent intervals. Finally, after mail-back return of the units, the data are processed to include variables such as travel speed by road classification, trip distance, and trip time. The unit allows for collection of travel data over several days to avoid potential short-term, survey-induced travel behavior changes.

This method of data collection has two potential benefits: improving the quality of travel behavior data, and reducing respondent burden, e.g., time on the telephone for reporting travel. Using GPS technology, while increasing privacy concerns, may improve overall survey responses in travel behavior studies. Technical issues for hardware, software, and comparison of results between self-reported travel and machine-recorded travel are provided.

Keywords: GPS, travel behavior, household travel surveys

INTRODUCTION

Personal travel and how it changes is of continuing concern to transportation planners and policy makers. Information about daily travel patterns and trip purposes, time of day decisions, mode choice decisions, and trip chaining decisions, are generally captured using self-reported information using a telephone recall method, or some kind of diary.

Transportation professionals and other users of the collected data surmise that people likely omit very short trips using self-reported methods. The current trend in collecting this type of data is to use an activity, rather than a travel diary, to attempt to both capture these short trips as well as to identify at-home activities that are substituting for traditional at-work activities. Nonetheless, self-reporting is used for this approach as well. Other problems with self-reporting include the tendency to round travel times to 10, 15, and 30 minute intervals.' Similar tendencies to round may be occurring in reporting trip distances as well. It may be that overall, VMT reporting is fairly complete using self-reporting methods, but that people neglect to report the short stops made during a journey, like stopping at the post office, ATM, or video store. Another issue with the trend toward activity reporting is the burdensome nature of telephone interviews that are averaging close to one hour per household for a l-day household travel survey.[2]

Vehicle instrumentation, including a GPS has been used in various Intelligent Transportation Systems (ITS) projects, for example in the Orlando TRAVTEK project, the Chicago ADVANCE project, and an EPA-sponsored research project at Georgia Tech. In the TRAVTEK and ADVANCE projects, GPS has been used to assist drivers in routing. That is, the GPS "knows" where the vehicle currently is, and the on-board computer can then "direct" the driver to their destination, potentially with the ability to include real-time information to direct the driver around congestion or accidents. These two projects rely on specially designed vehicles and combine GPS with other in-vehicle instrumentation (such as transmission sensors) to support dead-reckoning or map-matching techniques to pinpoint vehicle position. In the Georgia Tech project, the transponders are attached to personal vehicles to also provide information on engine operations and emissions.

This project would combine self-reported information with GPS recorded information and will provide recommendations about the potential usefulness of this technology for measuring changes in personal travel behavior. This technology has the potential for both improving the quality of data on travel behavior and reducing respondent burden for reporting this behavior.

OBJECTIVES

This project has three overall objectives.

1. Develop a method and hardware to integrate GPS technology with self-reported travel behavior to improve travel behavior data.

2. Document the differences between self-reported travel and GPS recorded travel and document the pros and cons of each method.

3. Determine potential for using GPS technology with regional and national travel behavior surveys, with particular regard to subjective responses to privacy.

The project is being conducted in three phases. Phase One defined a functional specification for the data collection device and compiled vendor and other technical information about GPS receivers, hand held and palm top computers and personal digital assistants (PDAs), and other equipment that might prove useful in this application. Phase Two performed a series of bench tests using several GPS receiver configurations to test the ability of the GPS equipment to collect position data that would be useful to support the personal travel data studies. Phase Three of the project is a larger field demonstration of the complete data collection device, collecting actual data from at least 100 households for subsequent analysis.

GENERAL DESCRIPTION OF THE DATA COLLECTION UNIT

The result of the Phase One activity established the general definition of the data collection device. The key components include the GPS receiver, the user interface, and the control unit. The user interface and control unit are made up of a single component, a hand held PDA equipped with touch screen for user inputs. The GPS receiver will likely use PCMCIA technology with an antenna mounted on the vehicle dashboard or roof top.

Operationally, the data collection unit is envisioned as a “plug and play” concept, requiring minimal installation and set up effort on the part of the user. The touch screen user interface, to be used for the self-reported portion of the travel information, is being designed to mimic the operation of an ATM, which is very familiar technology for a large segment of the population.

Travel data would be collected over a period of five to six days. Both user inputs and GPS position data would be stored internally or on a PCMCIA memory card. Principal power for the unit would be supplied via the vehicle’s cigarette lighter, with internal batteries to sustain the unit’s operating system when the vehicle is inoperative. The unit’s control software is designed to collect GPS data only when the vehicle is operating to conserve available memory capacity, and to place the entire unit in a “sleep” mode when the vehicle is not operating in order to conserve the internal batteries. This operating protocol will be fully tested before use in the broader field demonstration.

BENCH TEST OF GPS CONFIGURATIONS

Phase two of the project examined two issues. First, can the GPS positional data be collected with the continuity required for the personal travel survey using only a GPS receiver? There are many obstructions (overpasses, tall buildings) to the line-of-sight reception of the GPS signals and there is no opportunity for reliance on a second, independent positional data source (such as dead reckoning).

Second, what type of GPS receiver technology is better suited for this application? There is a wide variety of GPS receiver and ancillary equipment available. Phase two focused on a series of bench tests in order to address these two questions.

Receiver Selection

Three relatively high-performance, low-cost, off-the-shelf GPS receivers were chosen for use in the bench tests. The receivers were generally representative of existing, general-use GPS receiver technologies. The receiver set was comprised of a low-power 5-channel PCMCIA Type II receiver, a powerful 12-channel all-in-view serial kit receiver, and a 3-channel integrated receiver-antenna serial reception unit. Table 1 provides a brief summary of characteristics descriptive of the three GPS technologies.

Table 1. Features of the GPS Receivers Used in the Bench Tests

Receiver Feature	GPS Receiver		
	All-in-view Serial Receiver	PCMCIA (Type II) Receiver	Integrated Receiver & Antenna
Horizontal Position Accuracy	30 meters per axis (with SA inactive) 100 meters per axis (with SA active) <3 meters per axis (with differential correction)	50 meters per axis (with SA inactive) 100 meters per axis (with SA active)	50 to 100 meters
rime-to-First-Fix (TIFF)	5 to 10 minutes (almanac initialization) <60 seconds (with current almanac, position, time) <30 seconds (with current almanac, position, time, ephemeris)	30 seconds to 8 minutes	15 to 30 minutes (almanac initialization) 30 seconds to 2 minutes (power up)
Signal Reacquisition rime (typical)	2 sec (60 sec obscuration) 10 sec (60 min obscuration)	<l 0 sec (single satellite obscuration of < 15 sec)	not listed
Number of Tracking Channels	12	5	3
Satellites Tracked	all in view	9	8
Message Frequency	1 per second	1 per second, resettable 1 to 5 second intervals	1 per second, resettable to 5 or 10 seconds
Message Protocols	NMEA 0183 Proprietary Binary	NMEA 0183 Proprietary Binary	NMEA 0183 Proprietary Binary
Unit Size (inches)	4W x 6L x 1.5H	2.2 W x 5.4 L x 0.25 H	3.2W x 5L x 1.7H
Unit Weight (lbs)	1.3	0.2	0.75

The three receivers were configured into different test arrangements for the purpose of making comparisons. These configurations focused on using different GPS antennas, using different GPS antenna mount locations, and differential correction of the GPS data. Table 2 illustrates the various test configurations used in the bench tests.

Table 2. Test Configurations for the Bench Tests

Test Configuration	GPS Receiver	Antenna Type		Antenna Mount		Differential Correction	
		Active	Passive	Roof	Dash	Yes	No
#1	Integrated Receiver & Antenna				✔		v
#2	PCMCIA (Type II)		✔	✔			v
#3	All-in-view Serial	✔		✔			v
#4	All-in-view Serial	✔		✔			v
#5	All-in-view Serial	✔			✔		v
#6	All-in-view Serial		✔	✔			v
#7	All-in-view Serial	✔		✔		✔	

Seven bench test trials were performed to collect data over the test route. In trials #l through #3, each of the three receivers was configured in an arrangement which was thought to yield the best performance or was most likely to be used because of its inherent capabilities. Trials #4 through #7 explored different configurations using only the 12-channel serial receiver box. Differential corrections were made available to the 1 2-channel GPS receiver using a special cable provided with the receiver development kit. The differential corrections were provided through a separate, battery-operated pager-type FM subcarrier receiver, capable of providing sub-meter accuracy corrections.

Test Route

All seven test configurations used the same test route. The route was chosen previous to the bench tests in an effort to be as representative as possible of the travel segments and roadway obstructions afforded in the metropolitan Columbus, Ohio area. Some examples of included travel segments are

- older neighborhood with mature trees and relatively narrow streets,
- newer subdivision-style neighborhood with typically wider streets,
- suburban business district with relatively wide streets,
- central business district streets in an urban “canyon,” and
- state route limited access and interstate highways.

Some obstructions that are featured in the test route included natural terrain (e.g., hills and trees), manmade structures (e.g., short, tall, and skyscraper-type buildings), and overhead structures (e.g., automobile overpasses, rail trestles, and pedestrian walkways). The test route travel distance is approximately 19 miles and travel time is 45 to 60 minutes, depending on time of day and traffic conditions.

Bench Tests

The same type of data was collected for each receiver configuration at the same rate so that comparisons across receiver configurations could be made. These data were collected from each receiver at 1 pulse per second (1 Hz) and recorded directly to the control unit hard drive. The same control unit, a laptop PC with a 486 MHZ processor, was used in each trial. The GPS receivers were powered through the test vehicle cigarette lighter port, except for the PCMCIA receiver. The PCMCIA receiver was powered directly from the laptop PC, which was powered by its own NiCad battery.

Prior to the tests, each of the receivers was programmed to output a common RMC NMEA 0183 ASCII text output message. RMC is a standardized NMEA 0183 output message which delivers a set of the recommended minimum specific GPS data. These specific data includes time, date, position, course, and speed information. Though all of the receivers could be programmed to provide a more efficient binary output of raw data, NMEA ASCII output was chosen to facilitate the bench tests and subsequent data analyses, principally for the following reason.

The NMEA 0183 output message format is standardized. This is not true of the binary output messages provided by each receiver, where message format was proprietary and differed significantly in format from manufacturer to manufacturer. Working with a standardized output permitted a single, internally-developed data manipulation program without making modifications for each receiver. These data manipulations consisted of cleaning up bad records (data skip, message appendages, records taken during a loss of fix, etc.), making distance calculations, and translating output messages to position data files which could be later read by GIS plotting software.

Because binary output generally can store the same information more efficiently, actual GPS/PTS field tests will likely use a binary output message format since only one type of receiver is used.

Issues Regarding the Collected Data

There are several factors that prevent the bench trials from representing identical conditions for each of the receiver configurations.

First, the bench test trials were conducted over a number of days. Each trial typically lasted 50 to 55 minutes and consumed over an hour from pre-trial setup to securing the data following each trial. Consequently, the different geometries of the satellites in view (and of those satellites being used to obtain position information) relative to the GPS receiver affected the positional calculation for each receiver. Because of the rapidly changing geometry of the NavStar satellites over time and days, this reality could not be avoided.

Second, the length of each trial was somewhat dependent upon the traffic conditions along the test route. Relatively small changes in the amount of traffic experienced in the test route could significantly affect travel time. While directcomparison of travel times over the test route are not possible due to the changing conditions, this is not a significant issue from the viewpoint of the bench tests.

Some additional factors that may have affected the comparability of the collected data include the uncertainty of the broadcast update rate for differential correction (only in Trial #7), the imposition of selective availability by the Department of Defense (which dilutes the accuracy of the GPS receivers), and potential interference to signal acquisition that may have emanated from the test vehicle (e.g., automobile electronics) or outside sources.

While these issues were identified and considered in the head-to-head comparison for the bench tests, they represent real conditions that will be present for any field data collection effort.

Results of the Bench Tests

These results are of two types. First are the calculated route and segment distances using the positional data obtained from the GPS receivers. Distance calculations were based on the one-second data collected during the tests, and additional files were created to simulate 3, 5, and 10 second data for additional distance calculations for the total route. All distance calculations were compared to the odometer reading of the vehicle used in the tests. The accuracy goal for the distance calculations is 5% of the total trip length or 1/4 mile.

The second type of result from the bench tests are observations drawn from a visual inspection of the positional point data (using TransCAD GIS plotting software) compared to a map of the test route. This result relates to the goal of identifying the specific roadways traveled based solely on the positional data.

Distance Calculations

Table 3 contains the error in calculated distance for the entire test route and different data collection intervals (simulated in these analyses). A general observation across all test configurations is that shorter collection intervals (i.e., more data collected) result in a greater error in the calculated travel distance. The shaded boxes in the table identify those distance calculations that do not meet the stated accuracy goal.

Table 3. Distance Calculation Errors for the Entire Test Route (19 miles)

Data Interval	Bench Trial						
	#1	#2	#3	#4	#5	#6	#7
1 second	3.9%	11.5%	5.5%	3.4%	9.5%	4.7%	6.9%
3 second	3.2%	7.6%	4.9%	3.3%	8.8%	4.5%	5.6%
5 second	1.1%	6.3%	4.6%	2.8%	8.5%	4.2%	4.7%
10 second	1.4%	5.0%	3.8%	2.2%	6.9%	3.6%	2.9%

More frequent data are desirable to determine receiver position and ascertain which roadways are traveled. However, the positional data from a stationary receiver (such as when a vehicle is stopped at a red traffic signal) do not focus on a stationary point. These data are near the stationary point, but individual positional records are scattered around the location within an area dictated by selective availability and the accuracy of the individual receiver (which could be ±100 meters). These position errors associated with each record add up arithmetically when performing point-to-point calculations to determine travel distances. The same effect is seen in all cases, including trial #7 which is differentially corrected data.

Table 4 shows the errors for calculated distances in the individual route segments. The ¼ mile error percentage is shown for reference and the shaded boxes identify those calculations that did not meet the accuracy goal. The greatest errors observed in the calculated distances are observed in test route segments where line-of-sight challenges were the most formidable (e.g., downtown urban canyon, segments #2 and #3). This is an expected result. All of the test configurations performed well outside these two segments, and test configuration #1 and #4 performed well even in the urban canyon.

Table 4. Distance Calculation Errors for Individual Segments of the Test Route (1-second data)

Route Segment	¼ mile error	Bench Trial						
		#1	#2	#3	#4	#5	#6	#7
#1 (1.85 miles)	13.5%	2.7%	8.1%	1.6%	4.3%	3.8%	0.5%	7.6%
#2 (1.85 miles)	13.5%	1.1%	50.3%	6.5%	4.3%	65.4%	23.8%	28.1%
#3 (1.20 miles)	20.8%	19.2%	64.0%	34.1%	3.3%	7.5%	6.7%	9.2%
#4 (7.60 miles)	3.3%	4.6%	2.6%	3.6%	3.6%	3.7%	3.2%	3.8%
#5 (1.40 miles)	17.9%	0.7%	1.4%	1.4%	0.7%	1.4%	1.4%	7.1%
#6 (5.10 miles)	4.9%	1.6%	4.5%	3.9%	3.3%	2.2%	2.4%	2.9%

Another aspect of performance is important in comparing the test configurations. Each bench trial had some corrupted data resulting from loss-of-fix and other record errors in the test file. For each test configuration, the data were scrubbed to remove these corrupt records, thus only non-corrupt records providing valid time, distance, and position data are included in the travel distance calculations. Table 5 shows the number of valid data records from each test configuration for the individual route segments and the total route. The performance measure of interest is "percent of ideal," where "ideal" is defined as one valid record for every second of travel time. Test configuration #l exhibited poor performance compared to all other configurations, with just slightly over half of the collected records resulting in useful information.

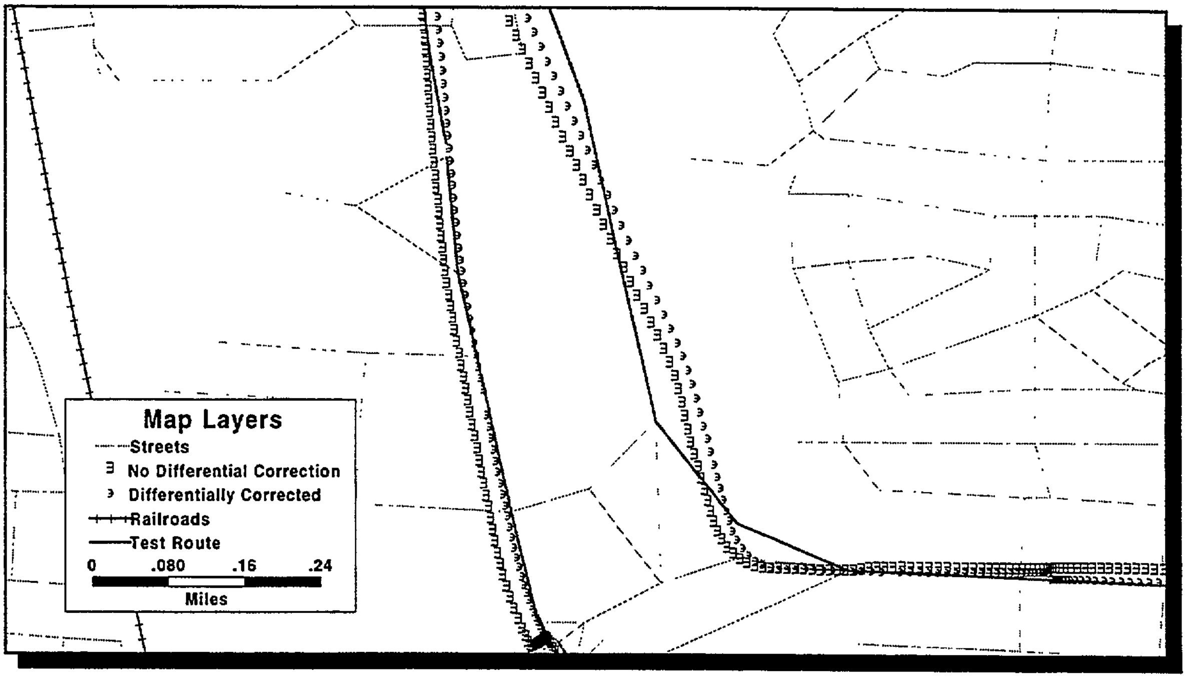
Table 5. Valid Records Collected for the Test Route (one-second data)

Route Segment	Bench Trial						
	#1	#2	#3	#4	#5	#6	#7
#1 (1.85 miles)	250	537	413	607	623	356	374
#2 (1.85 miles)	182	483	505	552	1,257	471	514
#3 (1.20 miles)	123	216	309	181	173	246	239
#4 (7.60 miles)	417	857	917	873	990	699	844
#5 (1.40 miles)	82	223	212	199	233	209	217
#6 (5.10 miles)	434	829	846	882	749	646	667
Total Route	1,483	3,140	3,197	3,289	4,020	2,622	2,850
% of Ideal	51.0 %	99.3 %	99.7 %	99.8 %	99.5 %	99.9 %	99.8 %

Positional Accuracy

Other projects using GPS in establishing vehicle location have generally relied on at least one other method of real-time measurement in addition to GPS for increased positional accuracy. Our ultimate purpose is to use the GPS data directly since additional real-time measurement methods are not feasible for a naive user-installed application. One method of increasing positional accuracy without increasing user difficulty is using differential GPS. Figure 1 shows a portion of test configuration ##l, using absolute GPS, and test configuration #7, the same configuration with differential correction, plotted on a Tiger file backdrop of the Columbus metropolitan area.

Figure 1. Comparison of Absolute and Differential GPS Test Data



Generally, the positional results were found to be consistent with published accuracies. Absolute data were found to always be within approximately 150 feet left or right of the Tiger file roadway center lines, and often much closer. The differentially corrected data were significantly more accurate and ranged from being plotted right on top of roadway stretches to a maximum of approximately 75 feet from centerline, about ½ the deviation exhibited by the absolute GPS plot.

Qualitatively speaking, the differentially corrected path plots always appeared to be significantly tighter around roadway bends and roadway changes. This is important in dense roadway areas, especially if those roads are traveled only for short distances. For these reasons, differential corrections may be necessary for broader use in field tests. However, the accuracy of the base map and the map-matching algorithm should be considered in conclusions related to positional accuracy. Also, as the Department of Defense relaxes the restrictions posed by selective availability, the absolute GPS data will become more positionally accurate.

Other Issues

Two issues related to the GPS receiver antenna were examined as part of the bench tests. These issues are active versus passive antennae and external versus internal mounts for the antenna. Also, the number of channels available in the receiver is important in establishing performance.

No significant advantages in positional accuracy were observed in test configurations that used active versus passive antennae. In fact, the term “active” is somewhat of a misnomer since the active antenna used in the tests was not driven by any power source. In general, this is not a significant issue for this application and using the antenna provided with the chosen receiver is probably the best approach to ensuring that the receiver will perform to manufacturer specifications.

Comparisons between test configurations using internally and externally mounted antennas generally shows that the externally mounted antenna test configuration performed better. Test configuration #4 (external, roof mount) and test configuration #5 (internal, dash mount) provide a direct comparison where the only difference in the test configurations is the antenna mount. The external mount is consistently better as measured by the distance errors for the entire test route (Table 3) and is substantially better in the urban canyon segment (Table 4). In general, the externally mounted antenna configurations do not have to contend with the line-of-sight blockages resulting from the test vehicle when encountering building obstructions and changes in direction of travel.

The biggest difference related to the number of channels is illustrated in Table 5. Test configuration #l had only three channels that could track up to eight satehites sequentially. This combined receiver-antenna is not suitable for external mounting, thus the results shown for test configuration #l may also reflect some effects from the internal mount as described above. However, the largest decrement appears to result from the number of channels since the other internal mount test (test configuration #5) recorded a high fraction of valid data. In general, the more channels available to track satellites, the quicker the receiver will recover from a loss-of-fix due to obstructed views and changes in direction of travel.

Power management is a significant issue because the objectives include collecting data over a period of five to six days. The 1990 NPTS data indicate that to capture 95% of vehicle trips, the unit would have to store up to 158 minutes (2.6 hours) of data per day. So, for a 6 day period, fully operational power is required for at least 15.6 hours. The device must be capable of sleeping and waking at the appropriate times both to conserve internal battery power and avoid draining the host vehicle battery. Good power management will also support more efficient use of available memory storage capacity by effectively shutting down the GPS unit when the vehicle is not being used.

Conclusions from the Bench Tests

The bench tests permit several conclusions related to the data collection unit.

The GPS data can be collected with sufficient continuity for personal travel survey information. One-second data is probably needed to provide a complete track of the route driven, especially when the travel is at relatively high speed, such as on an interstate highway. This one-second trace is also useful for determining the functional class of highway traveled. Less frequent data, however, is sufficient for collecting travel distance and travel time. In these test, the errors associated with travel distance calculations were consistently smaller when less frequent data were used.

Differential GPS data provides increased positional accuracy that may be required to identify the highway functional class for each trip. Differential GPS would almost certainly be required if the post-processing to identify functional class is performed manually. If the post-processing can be performed automatically, absolute GPS may be sufficiently accurate for this identification. Differential GPS offers no advantage for the point-to-point travel distance calculation.

The chosen equipment must have sufficient tracking channels to consistently collect the GPS positional data. In these tests, both the five-channel and 12-channel receivers demonstrated good performance. Also, a roof-mounted antenna is the best option to avoid some line-of-sight tracking issues and to give the receiver a better opportunity to collect the positional data.

PLANS FOR PHASE THREE

Phase three of the project is now underway. The overall objective of phase three is to demonstrate the ability to improve the quality of travel behavior data through automatic data collection.

The principal data of interest are vehicle occupancy and trip purpose. The user interface to collect these data using touch screen menus is currently being developed.

Vehicle occupancy will identify the driver and the passengers in the vehicle. This entry will identify the individual household members and include a count of non-household members. The 1990 NPTS data show that for over 90 percent of vehicles, there is a primary driver? Many trips (67%) are also drive-alone: thus it is probably not much of a burden for the respondent to identify the driver and passengers. Since each household will be individually recruited to participate in the demonstration, the data collection unit will be personalized to show the names of the individuals in the household on these menus, making it easy to select the driver and household members who are in the vehicle. This approach should facilitate data entry through familiar cues rather than an abstract menu.

Trip purpose, on the other hand, is much more difficult to organize and to program into a simple menu system. The current design includes a two-stage trip purpose selection menu, with a total of 15 purposes for the driver, and 15 purposes for passengers. Results of recent activity-based self-reported diaries were used to select those activities that appear most frequently and to include these activities on the primary screen shown in Table 6[5,6] Since the unit is being designed for vehicle drivers, trips to day care and pre-school activities are confined to passenger trip purposes, shown in Table 7. These choices will be adjusted after additional testing, before use in the actual field test.

Table 6. Trip Purpose Menus for the Driver

Primary Menu	Secondary Menu Choices
Pick Up or Drop Off Passengers	-Pick Up Passenger -Drop Off Passenger
Work or School	-Work Place -Work-related Business -School, College, University
Shopping & Personal or Household Business	-Shopping -Errands and other personal business, such as bank, post office, dry cleaner, video rental, barber, car repair, etc.
Eat Out	*none*
Social or Recreational	*none*
Medical or Dental	*none*
Return Home	*none*
Other	-Religious Activities -Volunteer Work -Community Meetings, Political or Civic Events -Other

Our goal is to have respondents select their immediate destination on the trip purpose menu. This immediate destination may differ from their ultimate destination. Trip chaining has become an important topic in the travel behavior research community. Some research indicates that as many as 30 percent of trip chains are complex, containing more than one stop.[7] It is difficult for someone in the general public to determine a trip purpose, if their ultimate destination is to return home after work, but with a stop at the dry cleaner along the way. The respondent may select "Return Home" for both trips, instead of selecting "Personal Business - Errands" for the first destination to the dry cleaners.

Telephone interviewers can probe respondents for corrections during a telephone interview, but the in-vehicle palm top unit will not have the same ability to judge reasonable choices. Reminding respondents of their last choice when a new trip purpose is selected, and allowing the respondent to correct their choice, may be one way of reducing these errors.

The in-vehicle data collection units are planned to be in operation for 5 or 6 days in each vehicle. A "recall" telephone interview with the respondent will be conducted on one day during the data collection period. This telephone interview will be similar to the travel day portion of the 1995 Nationwide Personal Transportation Survey, where information on trips for a 24-hour period is collected. The recalled travel data will be compared to the machine-recorded travel data, in terms of overall number of trips, trip purpose, travel time, and travel distance. In addition, the machine-recorded travel data will allow measurement of travel distance for each trip by roadway functional class, something that respondents are not able to report.

Table 7. Trip Purpose Menus for the Passenger

Primary Menu	Secondary Menu Choices
To Day Care or Preschool	*none*
Go Along for the Ride	*none*
Work or School	-Work Place -Work-related Business -School, College, University
Shopping & Personal or Household Business	-Shopping -Errands and other personal business, such as bank, post office, dry cleaner, video rental, barber, car repair, etc.
Eat Out	*none*
Social or Recreational	*none*
Medical or Dental	*none*
Return Home	*none*
Other	-Religious Activities -Volunteer Work -Community Meetings, Political or Civic Events -Other

Finally, the user's acceptance of this type of data collection device is key to the future use of this technology for large scale data collection efforts. Ease of use issues are being addressed by incorporating a touch screen interface in the device for user input. Operationally, the device will mimic a ATM machine which is probably familiar to most of the people that will participate in the field test.

Many other differences exist between this automated data collection device versus a travel diary or telephone interview. Since this device essentially tracks every movement of the vehicle (and thus the person), privacy issues are expected to be raised as a point of concern for the respondent. There are other concerns, principally liability issues, related to the physical installation of a device in a private vehicle. These and other issues will continue to be examined as a part of this technology demonstration in phase three.

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