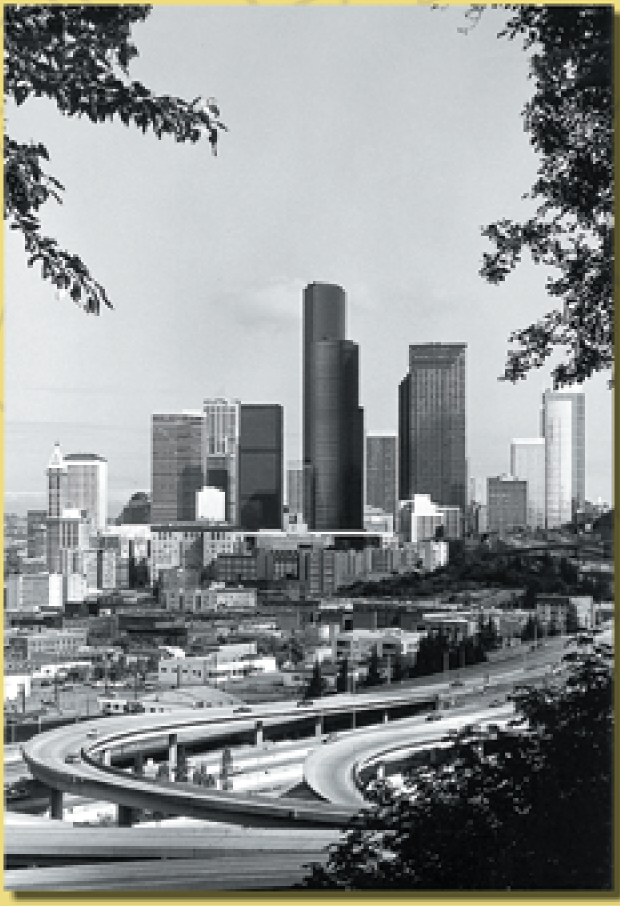
# Travel Time Data Collection Using Global Positioning System Technology

## Revised Draft Report

**Prepared for**

Puget Sound Regional Council
PSRC



**Prepared by**

D&M GROUP
BRW
A DAMES & MOORE GROUP COMPANY

**In association with:**

**Texas Transportation Institute**
**KDD and Associates**
**Innovative Transportation Concepts**

**July 3, 2000**

# TRAVEL TIME DATA COLLECTION USING GLOBAL POSITIONING SYSTEM TECHNOLOGY

## *FINAL REPORT*

**Prepared for:**

Puget Sound Regional Council

**Prepared by:**

BRW, Inc.

**In Association with:**

Texas Transportation Institute
KDD and Associates
Innovative Transportation Concepts

**August 2000**

# TABLE OF CONTENTS

**Chapter** **Page**

# List of Figures

# List of Tables

# List of Tables, continued

# EXECUTIVE SUMMARY

## Project Objectives

The primary objective of this study was to develop a methodology for making planning level estimates, specific to the Puget Sound Regional Council ("Regional Council") study area, of the resource requirements of collecting travel time data using global positioning system (GPS) technology. The Regional Council Study area consists of King, Snohomish, Pierce and Kitsap Counties in the Central Puget Sound region of Washington State. Further, based on the estimated requirements, the value of the information yielded, and other lessons learned based on field experience with the GPS technique, the study was to recommend either use of manual methods or the GPS approach. A secondary objective of the study was to collect travel time data using the GPS technique, for subsequent planning and analysis purposes.

One of the primary considerations driving the Regional Council's interest in travel time data collection techniques is the need for congestion indicators for use in Congestion Management System planning. The GPS data collection technique was selected for the following reasons:

- It uses portable GPS receivers which can automatically record vehicle position, speed and time along the entire length of the route at short time intervals, even as often as every one second, and within an accuracy of up to one meter.

- The GPS positional data is readily compatible with the Regional Council's GIS architecture. This makes it possible to display individual vehicle trajectories on the Regional Council's digital street map and to apply geographic analysis techniques to obtain travel time and speed estimates for individual highway segments and routes. It also facilitates the production of tabular reports and maps documenting travel times and speeds on the Congestion Management System roadway network.

- In comparison to traditional, manual test vehicle techniques, the GPS data collection technique is relatively operator independent, only one person is needed in the vehicle, and the accuracy and detail of the data are considerably better.

The GPS data collection approach lends itself quite naturally to the application of powerful new technologies, particularly those that involve wireless communications, which have the potential to improve the coverage and quality of the data gathered by the Regional Council. Examples of possible applications include area-wide travel time data gathering, origin-destination studies, emissions monitoring and modeling and before-and-after studies.

## Project Approach

A proposed GPS methodology was developed and evaluated in a travel time data collection field test. The methodology included: selection and procurement of GPS equipment; identification of procedures for determining sample size requirements (i.e, number of runs needed per segment); procedures for estimating resource requirements (i.e., number of days and GPS units needed); and procedures for analyzing and reporting data using the Regional Council's Geographic Information System.

Estimates were developed of the resources required to collect travel time data for both the field test corridors and for all interstate and principal arterial streets in the region, using assumed values for key parameters. The observed or actual values of these key parameters were then calculated based on the field test results and the estimates were revised using the new, more accurate values.

## Conclusions and Recommendations

Advantages Relative to Alternative Techniques

- Overall, the GPS technique investigated in this study appears to be the best approach for limited scale travel time data collection. However, for major region wide data collection it is recommended that a different approach be utilized. The recommended approach should eliminate the need for paid vehicle operators and should feature wireless transmission of GPS data from the vehicle to a remote storage location, eliminating the need to store the data on board the vehicle. There are several emerging wireless technologies that enable such an approach, in some cases using GPS, as further discussed below.

- Although still fairly resource-intensive, the GPS technique requires half as many field labor resources as the manual test vehicle approach and it produces more data and more accurate data.

- GPS coupled with GIS is a powerful combination and a justification for using the GPS approach. Through the field test effort, the Regional Council has already developed some familiarity with, and to some extent demonstrated the capabilities associated with GIS and GPS travel time data. Geographic information systems provide a common information platform, allowing travel time information to be easily displayed and analyzed in conjunction with other data, and travel time information in GIS can easily be shared with other organizations.

- The GPS approach that was tested is generally cost-effective only for smaller study areas; for large scale, system wide performance monitoring, the applicability of alternative techniques utilizing emerging technologies should be considered. Two options show particular promise, both of which eliminate the need to pay drivers. The first approach is cellular telephone tracking using emerging triangulation or pattern recognition techniques. Due to the relatively high cost of this technique it is best pursued in partnership by a number of different agencies or organizations. This approach is not cost-effective if travel time data for regional planning is the only data collected. The second approach is to equip volunteer drivers with a quantity of hand-held devices, such as palm top computers, equipped with GPS receivers. The devices would automatically collect and wirelessly transit GPS location information back to a central location. Both techniques have strengths and weaknesses and should be further investigated.

GPS Equipment and Data Collection Protocol

- The basic GPS technique is fairly well established and reliable, and although it eliminates most sources of error, it does not eliminate the need for operator training and diligence.

- The Regional Council should continue to use and perfect the GPS approach. When scheduling major data collection efforts, the status of the US Coast Guard's GPS differential correction service, and the status of the GPS satellites, should be verified. Information on the US Coast Guard differential correction service can be obtained at the web site, "www.navcen.uscg.mil". Information on the GPS satellite system can be obtained at the Shriever Air Force Base web site, "http://www.schriever.af.mil/gps/".

- Although GPS equipment sets have essentially become "off-the-shelf", a significant amount of effort can be required to install and fine-tune a particular equipment set. The Regional Council's experience with the Trimble Placer 455DR GPS units, the units purchased by the Regional Council but that were not available during the field test, supports this assertion. The de-bugging and fine tuning process has not been completed. To date, several difficulties have been encountered:

    - The claimed level of positional accuracy has not been achieved.

    - The dead-reckoning unit installation has proven challenging, requiring the installation of equipment that cannot be easily moved from vehicle to vehicle.

    - It has been difficult to consistently collect good data, possibly due to problems with the mounting of the accelerometer.

    - It has been observed that the dead reckoning unit must be properly calibrated at all times, since the dead reckoning signal is used continuously, not just when satellite communication is obstructed.

- The GPS units that were leased for use in the field test (Trimble Pathfinder Pros) are capable of and were found to achieve higher levels of positional accuracy than the units that were recommended based on the equipment review (Trimble Placer 455DRs, which have been purchased by the Regional Council). The leased units do not include dead-reckoning devices, which, although it eliminates the possibility of collecting data in areas where the GPS satellite signal is obscured by tall buildings, dense foliage, etc., it eliminates the complications and portability restrictions associated with the dead-reckoning devices. Given these considerations, in cases where data gaps are less of a concern than the accuracy and portability of the units—and therefore their adaptability to a range of other applications, including infrastructure inventories—the Pathfinder Pro units may be preferable.

- Drivers should note the cause of major delays, e.g., due to incidents, and utilize standard coding and naming conventions.

### Sample Sizes and Resource Requirements

- A formula was developed to estimate resource requirements that includes the following variables: sample size (number of runs required); route mileage; the number of GPS units to be used; and the number of miles that can be covered per data collection session per GPS unit/test vehicle. The formula does not include the following additional factors that can significantly increase the amount of time and effort required to collect a given amount of data: time lost between the end of one run and the start of the next run ("repositioning time"); runs that must be repeated due to invalid data (e.g., equipment failures or operator errors); and the unusable, "left over" periods of time in each data collection that are insufficient to make another run. The influence of these additional factors depends heavily on the structure of the data collection effort, and can be partially controlled. For example, as data collectors become more familiar with the GPS units and data collection protocols, the number of repeated runs due to invalid data will decrease.

- The field test results indicate that the resource requirements estimation formula underestimated the actual resources required by approximately one-half, due to the influence of the three factors that are not accounted for in the formula. Therefore, estimates made using the formula should be doubled.

- Travel time data collection using any sort of test vehicle approach is fairly labor-intensive and the resources required to collect data over large areas are considerable. This suggests that, like traffic count programs, travel time data collection efforts over large areas should be viewed as on-going rather than periodic, short-term activities. In terms of the application of GPS travel time data collection techniques to CMS monitoring, the results of this study indicate that collecting data for the entire Metropolitan Transportation System being monitored for the CMS would not be cost feasible. Therefore, it is recommended that data be collected on a limited number of corridors only, and that an initial screening process be developed that will allow the Regional Council to focus available resources on the most critical locations, e.g., the most congested, most traveled corridors.

- Consider the trade-offs between cost and data applicability carefully. Resource requirements are a function of a number of interrelated variables, and will vary considerably depending on the application, desired level of accuracy and validity. Ultimately, given limited resources, trade-offs must be accepted.

- Plan the study design in accordance with the specific intended uses of the data. The specific objectives of the travel time study will dictate the study design, and therefore the resources required to complete the data collection effort. Specific details of the travel time data collection methodology have significant implications for how the results can reasonably be applied. Segmentation of the analysis corridors is a key consideration that will impact the data collection methods and how the data can be used. Research (Quiroga and Bullock, 1998) and consultant team experience on other projects suggest that breaking corridors up into segments that can be driven in approximately 15 minutes is an effective approach which should be given consideration in future data collection efforts.

# 1.0 INTRODUCTION

## 1.1 Project Objectives

The primary objective of this study was to develop a planning level estimation methodology, specific to the Puget Sound Regional Council ("Regional Council") study area, that can be used to estimate the resource requirements of collecting travel time data using global positioning system (GPS) technology. Further, based on the estimated requirements, the value of the information yielded, and other lessons learned based on field experience with the GPS technique, the study was to recommend either use of manual methods or the GPS approach. A secondary objective of the study was simply to collect as much actual travel time data as possible using the GPS technique, for subsequent planning and analysis purposes.

## 1.2 Regional Council's Interest in Travel Time Data and Data Collection Techniques

The Regional Council's primary interest in travel time information is as a tool for developing and monitoring the effectiveness of the Congestion Management System (CMS). The CMS is a regional planning instrument mandated by the Intermodal Surface Transportation Efficiency Act of 1991 and continued by the current federal transportation act, the Transportation Equity Act for the 21st Century (TEA-21). As the Metropolitan Planning Organization for the Central Puget Sound, the Regional Council is responsible for the preparation of the CMS. The focus of the CMS is, as the name indicates, on roadway congestion. Throughout the field of transportation planning and operations, there is an emerging consensus that travel time is the most meaningful measure of congestion. Thus, the Regional Council is interested in identifying ways that regional travel time data can be cost-effectively collected and utilized in the preparation and monitoring of the CMS.

There are a number of different techniques available for collecting travel time data, including the test vehicle technique, license plate matching, probe vehicle techniques and a variety of emerging non-traditional techniques, including use of aerial surveillance. The test vehicle technique consists of driving the route and recording times at check-points and, depending on the purpose of the study, recording the reason for delays encountered along the route. This technique is by far the most common approach because it is simple to execute and yields detailed information.

Unfortunately, the test vehicle technique does have several limitations. Most importantly, although the technique is simple, it is resource-intensive, because it should be performed with two people in the test car, one to drive and one to record, and because the data is manually recorded (either with paper and pencil or on a laptop computer), considerable post-processing is required. These limitations led the Regional Council to consider more effective methods of data collection. Rejecting the other major options available, including license plate matching (resource intensive and limited data detail) and probe vehicles (requires expensive sensing equipment and not sufficiently proven), the Regional Council decided to further investigate a refinement of the test vehicle technique that is increasingly being utilized around the country: the global positioning system (GPS) test vehicle technique.

The GPS test vehicle technique uses a portable GPS receiver to automatically record the vehicle location and time at close intervals along the entire length of the route, even as often as every one second. The GPS technology uses satellites to triangulate the exact location of the receiver anywhere on the earth, to as much as a +/- 1-meter level of accuracy. The GPS technique has several major advantages, including:

- Only one person is required in the test vehicle—the driver—so labor costs for the field data collection are reduced by half.

- The technique is much more accurate, for a number of reasons. There is no inconsistency in precisely how travel times are noted relative to the check points (e.g., on the near-side or far side of intersections, etc.), either within a given run, or between different data collection personnel. Also, many of the numerous opportunities for data recording errors inherent in the manual technique, both in the field and in data reduction and manipulation, are eliminated since the data is automatically recorded in a digital format that does not have to be manually transcribed.

- Much more data is collected—as opposed to recording times at a few check points, times are recorded every few seconds, providing an extremely detailed and rich statistical picture of travel conditions.

- Vehicle location, speed and time information are digitally geo-coded, i.e., recorded in a format that digitally links the vehicle location and time with a real specific location along a roadway, and in a format that allows the data to be manipulated and displayed using standard Geographic Information Systems (GIS). A GIS is an extraordinarily powerful computer tool for mapping and analyzing geographic information, and is used extensively by the Regional Council.

Given the apparent benefits and emerging popularity of the GPS enhancement of the traditional test vehicle travel time data collection approach, the Regional Council identified the need to investigate its application in the Central Puget Sound area. This investigation—the subject of this study—includes development and field testing of a specific data collection methodology , establishment of the advantages and cost-effectiveness of the technique, development of tools for estimating the resources required to conduct data collection efforts of any given size, and determine the resources required to conduct a regional study on the scale needed to support CMS planning. In addition to these specific objectives, this study was also an opportunity to collect actual travel time data, which can be used in a number of planning and analysis applications.

As originally envisioned, this study was also to include some investigation of the data reduction and manipulation of GPS collected travel time data possible using GIS. As explained in Section 2.0, after it became apparent that all project resources would be exhausted reaching even the minimum goal of collecting two valid travel times per study route, plans in this area where significantly scaled back. As noted in the Conclusions and Recommendations section of this report, even though this study was not able to demonstrate the full potential for GIS manipulation of GPS travel time data, the potential in this area is considered widely established and must be counted as one of the most powerful justifications for continued use of the GPS approach.

## 1.3 Project Approach

The project consisted of the following five activities:

1. Develop Proposed Methodology

The state of the practice relative to GPS travel time data collection was reviewed and a specific proposed approach was identified, including specification of the type and configuration of GPS equipment, and basic approaches to inputting and analyzing the data using GIS.

2. Develop Resource Estimation Methodology and Estimates

Default travel time data collection resource requirement estimation formulas were developed for prototypical applications (e.g., resources required per mile of facility for freeways and arterials) and the resources required to perform a regional travel time study in the Regional Council area were estimated.

3. GPS Data Collection Field Test

A sampling of travel time data for corridors and segments throughout the Regional Council study area was collected, using the GPS technique. A preliminary analysis was conducted to calculate the observed values of key variables in the resource requirement estimation formulas developed in step 2.

4. Refine Cost Estimation Methodology and Estimates Based on Field Results

The default travel time data collection resource requirement estimation methodology developed in step 2 was refined using the observed values obtained from the data collection field test. This produced Central Puget Sound area-specific estimates that can be applied in the future to estimate the resources necessary to conduct travel time data collection efforts of varying extents. In addition, the initial estimate of the resources required to complete a Regional Council area-wide data collection effort was refined, again based on the results of the field test.

5. Develop Conclusions and Recommendations

Based on the research on data collection techniques and the lessons learned in the field test, overall conclusions and recommendations were developed, including a recommendation relative to the continued use of the GPS technique.

## 1.4 Organization of This Report

This report is organized according to the five basic project activities described above, and contains the following sections:

- Executive Summary
- Introduction
- Proposed Methodology
- Initial Resource Estimation Methodology and Estimates
- Field Test
- Refined Estimation Methodology and Estimates
- Conclusions and Recommendations

# 2.0 PROPOSED METHODOLOGY

This section presents a proposed Regional Council travel time data collection methodology using GPS, including specification of the type and configuration of GPS equipment, and basic approaches to inputting and analyzing the data using GIS. The focus is on those aspects of the overall travel time data collection methodology that are unique to the GPS technique, and currently unfamiliar to the Regional Council.

## 2.1 Rationale for the Basic GPS Test Vehicle Technique

The GPS refinement of the traditional test vehicle travel time data collection technique is increasingly popular. It's popularity stems from it's reduced field resource requirements (one person in the car instead of two), it's accuracy and consistency, the richness of the data collected and the ability to directly manipulate and analyze the data in a digital format using Geographic Information Systems. It is these powerful advantages in addition to those associated with the test vehicle technique in general that led the Regional Council to identify this technique as worthy of local application. Competing techniques, including license plate matching, probe vehicles equipped with automated vehicle identification (AVI) transponders, or emerging techniques such as aerial surveillance, were rejected either based on factors such as cost, lack of proven track records or inability to generate sufficient, and sufficiently reliable data. Having identified the GPS technique as the approach that currently demonstrates the greatest promise for application by the Regional Council, the focus turned toward development of a specific methodology for field-testing.

Overall, the basic GPS approach to travel time data collection has been relatively well established through application around the world—the required hardware and software is essentially "off-the-shelf" and relatively few major options exist. The specific approach described here is based on the work of a leading researcher in the area, Dr. Cesar Quiroga of the Texas Transportation Institute, a member of the study consulting team. The recommended methodology utilizes Dr. Quiroga's principles, adapted to the specific conditions of the Regional Council study area.

## 2.2 GPS Equipment

### Specification of GPS Equipment

The GPS and associated equipment required for travel time data collection is essentially "off-the-shelf", although fine-tuning of a specific GPS equipment set, including installation and de-bugging, can entail significant effort. In terms of the GPS equipment itself, there are only a few options or considerations that need to be addressed. These considerations include:

- Approach to differential correction
- Required accuracy
- GPS coverage limitations and the need for dead reckoning

### Approach to Differential Correction

The United States government operates the satellite system used by all GPS receivers. Up until May 2000, the government intentionally degraded the accuracy available to non-governmental users. In order to eliminate that intentional inaccuracy, and in order to enhance the overall accuracy, a technique known as differential correction has been used. Although selective availability has been turned off, differential correction still increases the level of positional accuracy.

There are two basic approaches to differential correction: real-time and post-processing. In real-time differential correction, the GPS receiver uses the differential correction signal it receives from either a third party, or from a base station operated by the user of the GPS receiver, to correct the raw signal. This correction is done in real-time during data collection. The post-processing approach performs the correction after the data has been collected and stored in it's raw form. The post-processing approach to data collection is generally more cumbersome but yields more accurate data.

In selecting either the real-time or post-processing approach to differential correction, the key considerations are whether the data collection agency has its own base station, which would allow for post-processing correction, and the cost and availability of a third-party differential correction signal, which is needed for real-time correction. ***Since the US Coast Guard provides a free differential correction signal in the Regional Council study area, because the Regional Council does not operate it's own GPS base station receiver, and because of the relative ease of the real-time approach, the real-time approach to differential correction was selected.*** For these same reasons, the real-time approach is the most common one for travel time data collection.

### Required Accuracy

More expensive GPS receivers provide more accurate location information than less expensive receivers**.** ***For travel time data collection, a positional accuracy of around 1-2 meters is sufficient***, which can generally be achieved at a cost of around $2,000 per receiver (exclusive of dead-reckoning, see below).

### GPS Coverage Limitations and the Need for Dead Reckoning

The satellite signal used by GPS receivers can be blocked to varying extents in tunnels, downtown "urban canyons" bounded by tall buildings, and in areas with heavy tree canopies. Where these conditions are present, it is necessary to supplement the GPS receiver with a secondary positioning system that can be used to fill in the gaps. The standard approach is the use of a dead reckoning (DR) device, which consists of a combination of sensors (heading unit, odometer sensor and back-up light sensor) that records the physical movements of the vehicle and that can be used to estimate locations within GPS gap areas. GPS receiver manufacturers also use the DR input to routinely enhance the positional accuracy of the GPS data beyond what differential correction can provide. ***It was determined that the potential for GPS data coverage gaps is relatively***

***high in the Regional Council study area and that a DR device is needed.*** DR devices generally increase the cost of the GPS set-up by between $1,000 and $1,500. Dead-reckoning devices can be somewhat complicated to install and operate. This was considered in the selection of the preferred methodology and should be considered in future implementations.

### Selection of GPS Equipment

Based on the preceding considerations, the following basic requirements were identified for the Regional Council GPS travel time data collection equipment:

- Real-time differential correction using the US Coast Guard signal
- Positional accuracy of +/- 1 – 2 meters
- Dead reckoning device to supplement the GPS signal, and to replace the signal in GPS coverage gaps.

Using these requirements, in addition to cost and ease of installation and use, a number of different GPS equipment sets were evaluated, as detailed in Appendix A. Based on the evaluation, a unit manufactured by Trimble, the Placer 455 DR, was identified as the preferred equipment. The specifications of this unit include the following:

- GPS receiver: Trimble Placer 455DR (L1 frequency, 8-channel)
- Update rate: 1 Hz (once per second)
- Differential correction: Beacon receiver (RTCM SC-104 format)
- Dead reckoning: Trimble heading sensor with attachments to vehicle odometer and backup lights (backup light is optional)
- Data storage capabilities: None (requires a laptop computer)
- Output signal format: NMEA-0183, TAIP, TSIP

For two reasons it was determined that all of the travel time data collection performed in the field test needed to be completed during Fall 1999: traffic conditions during this time of the year are considered to best approximate annual average conditions and Fall 1999 was the designated data collection period for the CMS (data is collected during the fall of every other year). Unfortunately the preferred equipment, the Trimble Placer 455DR units, could not be procured in time to be used in the field test. As a result, substitute equipment consisting of three Trimble Pathfinder Pro units were leased for the field test, at a cost of approximately $12,750. In the meantime, two Trimble Placer 455DR units were ordered, at a cost of approximately $4,000 each, and will be available for future use by the Regional Council.

The Pathfinder Pro units provide many of the same functions as the Placer 455DR units, although the Pathfinder Pros can provide better positional accuracy—sub-meter as opposed to the +/- 2-5 meter accuracy provided by the Placer units. Unlike the Placer 455DR units, however, the Pathfinder Pro units do not include dead reckoning devices, and therefore do not provide any means for obtaining location information in areas where the GPS signal is unavailable (i.e., obscured by obstacles). Given the necessities imposed by the project schedule, this limitation was accepted and the Pathfinder Pro units were used for the field test.

## 2.3 Determination of Sample Sizes

### Overall Considerations for Sample Size

The Relationship Between Sample Size and Resource Requirements

In the context of travel time studies, "sample size" refers to the number of runs on any given route (a route refers to a particular roadway segment, a particular direction of travel on that segment and a particular peak period within which the run is made). In order to reasonably generalize the results of the specific travel time runs, i.e., to assume that they fairly represent typical or average conditions, it is necessary to perform enough runs on any given route so that atypical variations are averaged out. Variations can result from high traffic volumes or other characteristics that create unstable and therefore highly variable conditions, fluctuations in traffic volumes within given peak periods, or high variability from day-to-day. As variation increases, the number of required runs also increases. The required sample size in turn dictates, assuming a study area of a given size, the total miles driven and the total hours of field staff labor, and is therefore one of the single greatest determinants of the cost of travel time data collection.

Given the direct and significant impact of sample size on cost, and since budgets are often essentially fixed, in practice it is often the case that available budgets dictate sample sizes, rather than the reverse. In order to obtain acceptable results with the available resources, trade-offs in the two user-defined determinants of sample size must be made. Therefore it is important to understand the individual influence of the determinants of sample size and the implications associated with the trade-offs that typically must be made.

The Determinants of Sample Size

Over the last 25 years, the traditional approach to determining how many runs are required on a given travel time route utilizes a formula developed by the Institute of Transportation Engineers. The basic formula takes into account the following primary factors:

- variability in travel speeds
- statistical confidence level to be achieved
- allowable error

### *Variability of Travel Speeds*

The variability in travel speeds is expressed as a range, the difference between the highest and lowest travel speeds for a given route. The range can either be estimated or calculated based on two or more test runs on the route in question. As noted in the section above***, the greater the variability (i.e., the larger the speed range), the more runs are required.***

### *Statistical Confidence Level*

The statistical confidence is a mathematical measure of how often the actual average travel speed on a given route will be within the speed range used in the formula. For example, if a confidence level of 75% is achieved, it means that 75% of the time, on average (for example 195 days out of 260 working days per year), the observed average speed on the route will be within the range used to calculate the required number of runs. Therefore, the analysis results will be applicable 75% of the time. There is a direct trade-off between the desired level of confidence and the required number of runs on any given route: ***the higher the level of confidence, the more runs are required***. There is no hard and fast rule as to the appropriate level of confidence, and ultimately it will reflect a compromise between confidence level and the cost of collecting the data.

### *Allowable Error*

Whereas confidence levels pertain to variability and the ability to generalize results across many days or peak periods, "allowable error" refers to the accuracy of the travel time estimate itself. When allowable error is high, the difference between the calculated average travel time or speed and the actual average time or speed on the route during the period in question, will be higher. As with confidence levels, there are no hard-and-fast rules for allowable error, although the Institute of Transportation Engineers suggests the ranges shown in Table 2.1.

**TABLE 2.1**
**INSTITUTE OF TRANSPORTATION ENGINEERS**
**SUGGESTED ALLOWABLE ERROR RANGES FOR TRAVEL TIME STUDIES(1)**

| **Application** | **Suggested Allowable Error (mph)** |
|---|---|
| Transportation planning and highway needs studies | +/- 3 - +/- 5 |
| Traffic operations, trend analysis and economic evaluations | +/- 2 - +/- 5 |
| Before and after studies | +/- 1 - +/- 3 |

As with confidence levels, the determination of allowable error is ultimately based on a trade-off between accuracy and resource requirements. ***The lower the allowable error, the more runs will be required, and therefore the higher the cost.***

## Proposed Methodology for Calculating Sample Size

The proposed approach to calculating required travel time sample sizes utilizes a set of easy-to-use look-up tables developed by Quiroga and Bullock (2) using a slightly modified version of the Institute of Transportation Engineers formula noted earlier. The tables have been created through the successive substitution of values for the three primary variables used in the formula: variability in travel speeds (expressed as a range), statistical confidence levels, and allowable error. Table 2.2 presents the four look-up tables, which identify sample size requirements (number of runs) for 99%, 95%, 85% and 75% confidence levels, speed ranges from 1 to 30 mph and allowable error from 1 to 5 mph. Although the 99% confidence level is not commonly used or needed, the sample size requirements are presented for reference.

Use of the look-up tables is the recommended approach to estimating sample sizes, given its simplicity. However, for any combination of values that fall outside of the ranges shown in Table 2.2, the formula that was used to produce Table 2.2 can be applied. This formula is shown in Table 2.3. ***Whenever possible, it is recommended that at least two test runs be completed for each route to yield observed speed ranges.***

## TABLE 2.2
## SAMPLE SIZE LOOK-UP TABLES FOR VARIOUS COMBINATIONS OF SPEED RANGES, CONFIDENCE LEVEL AND ALLOWABLE ERROR (Adapted from Reference 2)

a) Confidence level (1-α): 99.73%

| **Average Range $\overline{R}$** | | **Specified Permitted Error** e (±) | | | | |
|---|---|---|---|---|---|---|
| **(km/h)** | **(mph)** | **1.6 km/h (1 mph)** | **3.2 km/h (2 mph)** | **4.8 km/h (3 mph)** | **6.4 km/h (4 mph)** | **8.0 km/h (5 mph)** |
| 1.6 | 1 | 6 | 5 | 4 | 4 | 4 |
| 3.2 | 2 | 9 | 6 | 5 | 5 | 4 |
| 4.8 | 3 | 13 | 8 | 6 | 5 | 5 |
| 6.4 | 4 | 17 | 9 | 7 | 6 | 6 |
| 8.0 | 5 | 21 | 11 | 8 | 7 | 6 |
| 9.7 | 6 | 26 | 13 | 9 | 8 | 7 |
| 11.3 | 7 | 32 | 15 | 10 | 8 | 7 |
| 12.9 | 8 | 37 | 17 | 12 | 9 | 8 |
| 14.5 | 9 | 44 | 19 | 13 | 10 | 9 |
| 16.1 | 10 | 50 | 21 | 14 | 11 | 9 |
| 17.7 | 11 | 57 | 24 | 15 | 12 | 10 |
| 19.3 | 12 | 65 | 26 | 17 | 13 | 11 |
| 20.9 | 13 | 73 | 29 | 18 | 14 | 11 |
| 22.5 | 14 | 81 | 32 | 20 | 15 | 12 |
| 24.1 | 15 | 89 | 35 | 21 | 16 | 13 |
| 25.7 | 16 | 98 | 37 | 23 | 17 | 14 |
| 27.4 | 17 | >100 | 41 | 25 | 18 | 14 |
| 29.0 | 18 | >100 | 44 | 26 | 19 | 15 |
| 30.6 | 19 | >100 | 47 | 28 | 20 | 16 |
| 32.2 | 20 | >100 | 50 | 30 | 21 | 17 |
| 40.2 | 25 | >100 | 69 | 40 | 28 | 21 |
| 48.3 | 30 | >100 | 89 | 50 | 35 | 26 |

b) Confidence level (1-α): 95%

| **Average Range $\overline{R}$** | | **Specified Permitted Error** e (±) | | | | |
|---|---|---|---|---|---|---|
| **(km/h)** | **(mph)** | **1.6 km/h (1 mph)** | **3.2 km/h (2 mph)** | **4.8 km/h (3 mph)** | **6.4 km/h (4 mph)** | **8.0 km/h (5 mph)** |
| 1.6 | 1 | 4 | 3 | 3 | 3 | 3 |
| 3.2 | 2 | 6 | 4 | 3 | 3 | 3 |
| 4.8 | 3 | 8 | 5 | 4 | 4 | 3 |
| 6.4 | 4 | 10 | 6 | 5 | 4 | 4 |
| 8.0 | 5 | 12 | 7 | 5 | 4 | 4 |
| 9.7 | 6 | 15 | 8 | 6 | 5 | 4 |
| 11.3 | 7 | 18 | 9 | 6 | 5 | 5 |
| 12.9 | 8 | 21 | 10 | 7 | 6 | 5 |
| 14.5 | 9 | 24 | 11 | 8 | 6 | 5 |
| 16.1 | 10 | 27 | 12 | 8 | 7 | 6 |
| 17.7 | 11 | 31 | 13 | 9 | 7 | 6 |
| 19.3 | 12 | 34 | 15 | 10 | 8 | 6 |
| 20.9 | 13 | 38 | 16 | 11 | 8 | 7 |
| 22.5 | 14 | 43 | 18 | 11 | 9 | 7 |
| 24.1 | 15 | 47 | 19 | 12 | 9 | 8 |
| 25.7 | 16 | 51 | 21 | 13 | 10 | 8 |
| 27.4 | 17 | 56 | 22 | 14 | 10 | 8 |
| 29.0 | 18 | 61 | 24 | 15 | 11 | 9 |
| 30.6 | 19 | 66 | 25 | 16 | 12 | 9 |
| 32.2 | 20 | 71 | 27 | 17 | 12 | 10 |
| 40.2 | 25 | 99 | 36 | 22 | 15 | 12 |
| 48.3 | 30 | >100 | 47 | 27 | 19 | 15 |

c) Confidence level (1-α): 85%

| **Average Range $\overline{R}$** | | **Specified Permitted Error** e (±) | | | | |
|---|---|---|---|---|---|---|
| **(km/h)** | **(mph)** | **1.6 km/h (1 mph)** | **3.2 km/h (2 mph)** | **4.8 km/h (3 mph)** | **6.4 km/h (4 mph)** | **8.0 km/h (5 mph)** |
| 1.6 | 1 | 3 | 3 | 2 | 2 | 2 |
| 3.2 | 2 | 4 | 3 | 3 | 3 | 3 |
| 4.8 | 3 | 6 | 4 | 3 | 3 | 3 |
| 6.4 | 4 | 7 | 4 | 4 | 3 | 3 |
| 8.0 | 5 | 9 | 5 | 4 | 3 | 3 |
| 9.7 | 6 | 10 | 6 | 4 | 4 | 3 |
| 11.3 | 7 | 12 | 6 | 5 | 4 | 4 |
| 12.9 | 8 | 14 | 7 | 5 | 4 | 4 |
| 14.5 | 9 | 16 | 8 | 6 | 5 | 4 |
| 16.1 | 10 | 18 | 9 | 6 | 5 | 4 |
| 17.7 | 11 | 20 | 9 | 7 | 5 | 5 |
| 19.3 | 12 | 23 | 10 | 7 | 6 | 5 |
| 20.9 | 13 | 25 | 11 | 7 | 6 | 5 |
| 22.5 | 14 | 28 | 12 | 8 | 6 | 5 |
| 24.1 | 15 | 30 | 13 | 9 | 7 | 6 |
| 25.7 | 16 | 33 | 14 | 9 | 7 | 6 |
| 27.4 | 17 | 36 | 15 | 10 | 7 | 6 |
| 29.0 | 18 | 39 | 16 | 10 | 8 | 6 |
| 30.6 | 19 | 42 | 17 | 11 | 8 | 7 |
| 32.2 | 20 | 45 | 18 | 11 | 9 | 7 |
| 40.2 | 25 | 62 | 24 | 15 | 11 | 9 |
| 48.3 | 30 | 81 | 30 | 18 | 13 | 10 |

d) Confidence level (1-α): 75%

| **Average Range $\overline{R}$** | | **Specified Permitted Error** e (±) | | | | |
|---|---|---|---|---|---|---|
| **(km/h)** | **(mph)** | **1.6 km/h (1 mph)** | **3.2 km/h (2 mph)** | **4.8 km/h (3 mph)** | **6.4 km/h (4 mph)** | **8.0 km/h (5 mph)** |
| 1.6 | 1 | 3 | 2 | 2 | 2 | 2 |
| 3.2 | 2 | 4 | 3 | 3 | 2 | 2 |
| 4.8 | 3 | 5 | 3 | 3 | 3 | 2 |
| 6.4 | 4 | 6 | 4 | 3 | 3 | 3 |
| 8.0 | 5 | 7 | 4 | 3 | 3 | 3 |
| 9.7 | 6 | 8 | 5 | 4 | 3 | 3 |
| 11.3 | 7 | 9 | 5 | 4 | 3 | 3 |
| 12.9 | 8 | 11 | 6 | 4 | 4 | 3 |
| 14.5 | 9 | 12 | 6 | 5 | 4 | 3 |
| 16.1 | 10 | 14 | 7 | 5 | 4 | 4 |
| 17.7 | 11 | 15 | 7 | 5 | 4 | 4 |
| 19.3 | 12 | 17 | 8 | 6 | 5 | 4 |
| 20.9 | 13 | 19 | 9 | 6 | 5 | 4 |
| 22.5 | 14 | 20 | 9 | 6 | 5 | 4 |
| 24.1 | 15 | 22 | 10 | 7 | 5 | 5 |
| 25.7 | 16 | 24 | 11 | 7 | 6 | 5 |
| 27.4 | 17 | 26 | 11 | 8 | 6 | 5 |
| 29.0 | 18 | 28 | 12 | 8 | 6 | 5 |
| 30.6 | 19 | 30 | 13 | 8 | 6 | 5 |
| 32.2 | 20 | 33 | 14 | 9 | 7 | 6 |
| 40.2 | 25 | 44 | 18 | 11 | 8 | 7 |
| 48.3 | 30 | 58 | 22 | 14 | 10 | 8 |

## TABLE 2.3
## SAMPLE SIZE ESTIMATION FORMULA

$$n = \left[ \frac{t_a \overline{R}}{de} \right]^2$$

where:

n = required sample size
$\alpha$ = significance level
$t_\alpha$ = two-tailed t distribution statistic for a confidence level of 1-$\alpha$.
$\overline{R}$ = sample range based on available data
d = ratio of $\overline{R}$ to $\sigma$ (standard deviation of the population)
$\varepsilon$ = user-selected allowable error in the estimate of the mean speed (or interval half-length).

The ratio d is a function of n and, as a result, an iterative procedure must be followed to solve for n. The sample range $\overline{R}$ is computed as:

$$\overline{R} = \max_{i=1}^{m} v_i - \min_{i=1}^{m} v_i$$

where:

m = sample size of available data
$v_i$ = i^th^ segment speed observation of the initial study.

The $t_\alpha$ statistic is a function of n and, therefore, an iterative procedure must be followed to solve for n.

## 2.4 Data Reduction and Manipulation

As explained in Section 4.1, many of the approaches and suggestions identified in this section, which were developed prior to the data collection effort, were not fully applied during the actual data reduction and manipulation, but were substituted with more basic approaches that were more expedient in the very short term. The approach outlined here should be investigated in future data collection efforts.

### Data Reduction and Archival

Data Reduction

After each data collection session, the GPS data should be uploaded from the mobile data logger unit (or in the case of the Placer 455DR units, from the laptop) to a personal computer. To transform the GPS point data into segment travel times and average speeds, the GPS data must be converted to a relational database format (e.g., Microsoft Access). Some GPS equipment, including the leased Trimble Pathfinder Pro units used in the field test, include software (e.g., Pathfinder Office Suite) that can export GPS data in a Microsoft Access compatible format. The Placer 455DR units that the Regional Council will be using in the future can store data in a standard text file format that can easily be imported into Access. To make the data reduction process as efficient as possible an easy-to-use data reduction application should be developed for the Regional Council's GIS. The application would include a user interface that would allow the user of the application to load the GPS data files and click on segments so that the application determines the entrance and exit times and average speeds. The application should also display a number of points ahead so that the user knows that the next segment to click on is the next segment. The operator in a similar fashion would select successive segments.

A typical structure for the GIS-compatible relational database travel time data files is illustrated in Table 2.4. Once in such a format, the database can be spatially queried using GIS, and maps can be produced. The database can also be analyzed without using GPS, utilizing a wide variety of potentially useful non-spatial queries, including basic queries such as minimum, maximum and average speeds.

Data Archival

In addition to converting the raw GPS data into relational database files for subsequent analysis and reporting, it is important to archive the GPS data. Usually, the GPS data that comes from the field are stored in the form of ASCII (American Standard Code for Information Interchange) data files that contain GPS point coordinates, time stamps, and speeds. Table 2.5 shows sample records from a GPS data file.

Developing a robust data archival architecture requires good planning and a thorough-understanding of agency data needs and flows. In principle, a data archival procedure should be developed that includes GPS data files, zipped GPS data files, relational database tables, and GIS files. GPS data files could be easily stored on a compact disc (CD) using an appropriate directory structure. For archival purposes, all GPS data files should be compressed and stored in "zipped" files.

**TABLE 2.4**
**TYPICAL STRUCTURE FOR GIS TRAVEL TIME DATABASE (Adapted from Reference 3)**

| Database Field/Table | Description |
|---|---|
| Corridor Segments<br>(CORR_SEGMENTS) | Basic data about each segment, including a unique segment code, name direction, type, length, posted speed, and internal linkage to the database. Note that there are two references to the corridor: in the segment name field, and in the corridor code field. In most cases, the segment has the same name as the corridor. However, some roads that change name but are part of a defacto corridor can be studied as a group using the corridor code field. |
| Segment Types<br>(SEG_TYPES) | A lookup table that contains the linkage between the segment type codes included in table CORR_SEGMENTS and the corresponding segment type names. Segment types can be defined such as main, interchange, on-ramp, off-ramp, service road, and short link, and other. |
| Corridor Names<br>(CORR_NAMES) | Basic information about the corridors, including corridor name, beginning and ending points, and length. It also contains a field used to define the corridor function class. Length is actually a derived field based on the average of the cumulative lengths of all segments on both directions of travel along the corridor. |
| Functional Types<br>(FUNCT_TYPES) | A lookup table that contains the linkage between the corridor functional class codes included in table CORR_NAMES and the corresponding functional classes. Functional classes can be defined, such as Interstate, State Route, and Principal Arterial. |
| Segment Travel Time<br>(SEG_TRAVEL_TIME) | Summarized GPS-derived traffic related data. For each segment code, date, time, and vehicle ID, it stores travel time and average speed. For convenience, time in this table is expressed in seconds Universal Time Coordinated (UTC) since midnight. This table would contain the bulk of the data. |

**TABLE 2.5**
**SAMPLE GPS DATA ARCHIVAL STRUCTURE**

| ID | Date | Time (local time) | Latitude (°) | Longitude (°) | Speed (mph) |
|---|---|---|---|---|---|
| 552 | 9/30/99 | 8:06:12 am | 47.62533414 | -122.32874644 | 27.0 |
| 553 | 9/30/99 | 8:06:14 am | 47.62511558 | -122.32874562 | 28.1 |
| 554 | 9/30/99 | 8:06:16 am | 47.62488918 | -122.32874327 | 28.6 |
| 555 | 9/30/99 | 8:06:18 am | 47.62465802 | -122.32874153 | 29.0 |
| 556 | 9/30/99 | 8:06:20 am | 47.62442677 | -122.32874451 | 29.5 |
| 557 | 9/30/99 | 8:06:22 am | 47.62418518 | -122.32874253 | 31.2 |
| 558 | 9/30/99 | 8:06:24 am | 47.62392472 | -122.32873944 | 33.3 |
| 559 | 9/30/99 | 8:06:26 am | 47.62365359 | -122.32873821 | 34.2 |
| 560 | 9/30/99 | 8:06:28 am | 47.62338589 | -122.32874903 | 33.2 |

## Data Reporting

Once the data is reduced to the relational database format, and is archived, efficient reporting procedures should be developed. The specific reporting procedures and formats will depend on the purpose of the data collection effort, and could include simple tables, travel time contour maps and speed-distance or speed-time profiles. As noted above, traditional non-spatial queries and reporting of basic results can be performed using only a relational database software, such as Microsoft Access. For the preparation of maps, GIS can be a powerful tool.

### Color Coded Maps

The query used to generate the map could be modified to include different time periods or show other speed values such as median speeds, minimum speeds, and free flow speeds. However, in practice, large format color plots covering a 10x10 square mile area are typically plotted. These maps are particularly effective for explaining congestion problems at public meetings.

Once the GPS data points have been properly archived, they can be easily displayed on a GIS screen. The Regional Council uses an ArcView GIS platform. ArcView has a utility that allows users to import tables and generate point event themes based on X, Y coordinate pairs. After the GPS data are in the GIS environment, a number of tools can be used to obtain data needed to measure highway performance. For example, if the travel time between two points on a corridor is needed, the information icon can be used to display the data associated with the GPS points that are closest to the two points of interest. By subtracting the GPS time stamps, the net travel time on the corridor can be obtained.

For consistency and efficiency, it is advisable to define the location of all checkpoints by using a separate ArcView line or point theme. This way, a spatial query (using the Select by Theme function --Within Distance option) can be run to locate GPS points that are within the immediate vicinity of the checkpoints. This process can be made even more efficient by building a spatial join between the line/point checkpoint shape file table and the GPS data table being analyzed prior to running the spatial query. The reason is that a checkpoint identifier can be associated with every single GPS point based on proximity making the process of identifying those GPS points that are closest to individual checkpoints considerably easier.

Additional improvements in processing performance can be achieved by using an automated procedure to calculate travel times and speeds. At various times within the last five years several groups of consultants and researchers have worked to develop software aimed at automating the data reduction process. For the most part, the applications have been developed for specific GIS platforms may not be compatible with the ArcView platform used by the Puget Sound Regional Council.

Three recent efforts have been an application developed at Louisiana State University (LSU) using TransCAD (Quiroga and Bullock, 1999), a project undertaken by FHWA aimed at developing a generic data reduction utility in ArcView, and a current project at the Texas Transportation Institute (TTI). The application developed at LSU provides full automation to the data reduction process but the application was developed in TransCAD and, consequently, is not compatible with the ArcView platform. The FHWA project apparently had delivery problems and has not resulted in tangible usable products. The TTI project, which is headed by Dr. Quiroga, is part of a larger effort that involves the development of a graphical interface and associated procedures to fully automate the data reduction process in an ArcView-compatible environment. TTI anticipates having a preliminary version of the software by August, 2000.

### Base Map Preparation Procedure

A good vector base map with linkages to a database is essential for conducting travel time studies using GPS and GIS. This base vector map could be obtained by using digitized quad maps or TIGER files. However, such maps only provide a very crude representation of the corridors and their surroundings. A simpler and much more accurate approach is to drive probe vehicles over all study routes in both directions collecting GPS data at regular time intervals. The GPS data is then imported into a GIS map to create a directional centerline network map. By constructing this base map directly from GPS data, it can be guaranteed that the GPS data collected during future travel time studies will match the vector base map.

Traditional travel time studies record travel time and average speed between checkpoints along the study route. Checkpoints in the GIS map can be formalized by using two simple rules. First, a checkpoint is established at all physical discontinuities such as signalized intersections, significant unsignalized intersections, lane drops, on-ramps, off-ramps, and other geometric discontinuities. Second, the section of road between physical discontinuity checkpoints is segmented so that there are nominally *n* checkpoints every mile. Finally, a procedure is followed to link each of the discrete segments to a relational database. Assigning unique integer identifier numbers to each segment does this.

By creating these unique identifiers, each segment can have fixed data such as number of lanes and posted speed limit associated with it. It can also be used to index travel time data from travel time studies performed on different dates and times. These travel time studies would be conducted by driving a probe vehicle equipped with a GPS receiver and traversing the study routes during the morning and evening peak periods.

# 3.0 INITIAL RESOURCE REQUIREMENT ESTIMATES

As explained in Section 1.0, the primary objectives of this study were to: develop an estimation methodology (i.e., formulas or coefficients), specific to the Regional Council study area, that can be used to estimate the data collection resource requirements for travel time studies of various extents, and to develop an estimate of the data collection resources to conduct an area-wide travel time study in support of Congestion Management System Plan preparation. This was accomplished in three steps. First, a "default" estimation formula, utilizing assumed values, was developed and utilized to estimate the resources required for the area-wide data collection effort. Next, travel time sampling runs were performed throughout the region, with the objective to collect at least the two runs required per route to calculate the range of observed average travel speeds—a key input to the estimation of the required number of runs and therefore of the total resources required. Finally, the "default" estimation formula and initial area-wide data collection resource estimate were refined by substituting observed values from the field test. This section documents the first of these three steps.

## 3.1 Overall Considerations and Basic Estimation Methodology

There are at least two meaningful aspects to travel time data collection resource requirements: the total person-hours in the field, which indicates how much labor will be required, and the total duration of the field work in terms of days, weeks or months, which indicates how long the effort will take. Of course, these two variables both can ultimately be equated to a dollar cost. This study, however, focuses only on the labor-hour and duration expressions of resources.

The duration of the travel time data collection effort is a function of a number of factors, including:

- Duration of each data collection "session", e.g., peak period
- Required sample size, i.e., number of runs
- Distance that can be covered per data collection unit per session
- Number of days per week that data can be collected
- Number of data collection units (i.e., GPS equipped test cars and drivers) available
- Budget available

The basic formula for estimating travel time data collection resource requirements takes each of these variables into account. The formula has been configured to yield an estimate of the number of individual data collection "sessions" necessary, given a specified amount of data to be collected, with a specified number of data collection units available, and with each data collection unit/person completing a specified amount of work per session. In this context, a "session" equates to the time period under analysis, such as a 3-hour AM peak period, and therefore during which all data must be collected. The formula is shown in Table 3.1.

**Table 3.1**
**BASIC RESOURCE REQUIREMENT FORMULA:**
**SOLVING FOR NUMBER OF DATA COLLECTION SESSIONS REQUIRED**

$$\text{Number of Data Collection Sessions Required} = \frac{\text{\# of Runs Required} \times \text{Miles of Study Routes}}{\text{Number of Data Collection units} \times \text{Miles Covered Per Session Per Unit}}$$

*Notes:*

*Session = the time period under analysis, and during which all data must therefore be collected, for example the AM or PM peak period*

As shown in Table 3.1, the resource requirement estimation formula requires several inputs that themselves must first be calculated: the number of required runs must be estimated and the miles covered per session per data collection unit must be estimated. The approach to estimating the required number of runs is described in detail in Section 2.0. The technique includes collecting a minimum of two runs per study route in order to calculate an observed range of average speeds, and then utilizing look-up tables to determine the number of runs required given the observed speed range and desired level of statistical confidence and amount of allowable error. Estimation of the miles covered per session per data collection unit can be accomplished using the formula shown in Table 3.2.

**Table 3.2**
**FORMULA FOR ESTIMATING THE MILES COVERED**
**PER SESSION PER GPS DATA COLLECTION UNIT**

$$\text{Miles Covered Per Data Collection Session Per Data Collection Unit} = \frac{\text{Duration of Session (Hours)} \times \text{Travel Speed in Off-Peak Direction}}{1 + 1/\text{Travel Speed in Peak Direction (expressed as a fraction of the off-peak travel speed)}}$$

*Notes:*

*Session = the time period under analysis, and during which all data must therefore be collected, for example the AM or PM peak period*

As shown in Table 3.1, the formula to estimate the miles that can be covered per session, per data collection unit, is based on the duration of each session and the travel speeds in both directions. The "peak" direction is defined here as being the direction of travel with over 50% of the total two-way volume.

## 3.2 Facility Type-Specific Estimates

The resource requirement formulas shown in Tables 3.1 and 3.2 have been used to develop "default" estimation formulas that can be used to generate planning level estimates of travel time data collection resource requirements, for both urban and rural area roadways. The estimation formulas are default, or "generic", in that they utilize assumptions rather than observed values for the key inputs, including the number of runs required and the relationship of travel speeds to the posted speeds, in both the peak and off-peak directions. Refined versions of the estimation formulas, reflecting observed averages obtained in the field test, are presented in Section 5.0.

Table 3.3 presents the assumed values for sample size (required runs) and peak and off-peak direction speeds that have been assumed under the urban and rural scenarios and for the four types of roadway facilities: general use freeway lanes, HOV freeway lanes, 40-mph arterial streets and 35-mph arterial streets. The assumptions for number of required runs are based on past consulting team experience and the information in Table 2.2, which identifies the number of runs required based on speed ranges, confidence levels and allowable error. As shown in Table 2.2, at a level of confidence (85%) and with allowable error (+/- 5 mph) typical for a regional planning application, 3 to 4 runs are required for speed ranges up to 10 miles per hour. The assumptions for peak and off-peak speeds are based simply on posted speeds and general assumptions about prevailing conditions.

**TABLE 3.3**
**ASSUMED VALUES FOR DEVELOPMENT OF**
**INITIAL RESOURCE REQUIREMENTS ESTIMATES**

| | **Assumed Average Number of Required Runs** | | **Assumed Speeds by Direction** | | | |
|---|---|---|---|---|---|---|
| | | | **Off-Peak Direction Speed (mph)** | | **Peak Direction Speed (as a fraction of off-peak direction speed)** | |
| **Facility Type** | **Urban** | **Rural** | **Urban** | **Rural** | **Urban** | **Rural** |
| Freeways – general use lanes | 4 | 3 | 55 | 60 | .55 | .85 |
| Freeways – HOV lanes | 4 | 3 | 60 | 60 | 1.00 | 1.00 |
| Arterials – 40 mph | 4 | 3 | 35 | 40 | .50 | .85 |
| Arterials – 35 mph | 4 | 3 | 30 | 35 | .51 | .85 |

Table 3.4 presents default travel time data collection resource estimates for urban area roadways, expressed in terms of the number of data collection sessions required, given the assumed values shown in Table 3.3. Table 3.5 presents the same estimates for rural area roadways. The estimates in Tables 3.4 and 3.5 were developed using the equations shown in Tables 3.1 and 3.2. Tables 3.4 and 3.5 include estimates based on a range of possible values for two key variables: the miles of facility to be studied and the duration of the daily data collection period (i.e., the duration of the period being studied, such as a 1 hour AM peak hour). To determine the number of sessions required for combinations of factors not reflected in Tables 3.4 and 3.5, the calculations in Tables 3.1 and 3.2 can be used. Likewise, alternative versions of Tables 3.4 and 3.5 could easily be developed using different assumptions for number of runs required and speeds (see Table 3.3).

Note that if the data collection period occurs only once per day, as would typically be the case, such as with the AM or PM peak period, the number of data collection sessions required directly equates to the number of days of data collection required. Obviously, the values for number of sessions shown in Tables 3.4 and Table 3.5 can easily be converted to hours, weeks or months.

The values in Tables 3.4 and 3.5 were calculated assuming that one data collection unit is available. If more than one data collection unit is available, the estimates should be divided by the number of data collection units available. For example, if three data collection units are available, the data can be collected in one-third the amount of time (i.e., number of sessions) than would be required using only one data collection unit.

Tables 3.4 and Table 3.5 graphically illustrate the trade-off between the number of data collection sessions required and the amount of miles to be driven and the duration of the study period (i.e., maximum duration of each daily data collection period). Obviously the longer the study period, the fewer sessions will be required to collect a given amount of data. The duration of the study period is of course dictated primarily by the purpose and objectives of the data collection effort. In cases where true representations of peak periods are desired, such as for operational analyses, the study period must be defined narrowly to insure relative homogeneity of conditions within the period. As indicated in Table 3.4, the number of sessions (which equates to days) required to collect operational analysis data on urban area roadways, assuming a narrowly defined study period such as the peak 30 minutes, can be quite high. For example, depending on the miles of facility to be studied and the type of facility, it could take as much as 470 days, or 157 weeks, to collect the data.

## TABLE 3.4
## URBAN AREA DEFAULT TRAVEL TIME DATA COLLECTION RESOURCE REQUIREMENT ESTIMATES, EXPRESSED AS NUMBER OF DATA COLLECTION SESSIONS REQUIRED BY FACILITY TYPE

| **Facility Type & Duration of Data Collection Period** | **Number of Data Collection Sessions Required (Given Various Amounts of Study Area Mileage and Assuming One Data Collection Unit)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1 mi** | **5 mi** | **10 mi** | **30 mi** | **60 mi** | **150 mi** | **300 mi** |
| | | | | | | | |
| **Data Collection Period = 15 minutes** | | | | | | | |
| Freeway – general use lanes | 0.8 | 4.1 | 8.2 | 24.6 | 65.6 | 123.0 | 246.0 |
| Freeway – HOV lanes | 0.5 | 2.7 | 5.3 | 16.0 | 42.7 | 80.0 | 160.0 |
| Arterial – 40 mph | 1.4 | 6.9 | 13.7 | 41.1 | 109.7 | 205.7 | 411.4 |
| Arterial – 35 mph | 1.6 | 7.9 | 15.8 | 47.4 | 126.3 | 236.9 | 473.7 |
| | | | | | | | |
| **Data Collection Period = 30 minutes** | | | | | | | |
| Freeway – general use lanes | 0.4 | 2.0 | 4.1 | 12.3 | 32.8 | 61.5 | 123.0 |
| Freeway – HOV lanes | 0.3 | 1.3 | 2.7 | 8.0 | 21.3 | 40 | 80.0 |
| Arterial – 40 mph | 0.7 | 3.4 | 6.9 | 20.6 | 54.9 | 102.9 | 205.7 |
| Arterial – 35 mph | 0.8 | 3.9 | 7.9 | 23.7 | 63.2 | 118.4 | 236.9 |
| | | | | | | | |
| **Data Collection Period = 60 minutes** | | | | | | | |
| Freeway – general use lanes | 0.2 | 1.0 | 2.0 | 6.1 | 16.4 | 30.7 | 61.5 |
| Freeway – HOV lanes | 0.1 | 0.7 | 1.3 | 4.0 | 10.7 | 20.0 | 40.0 |
| Arterial – 40 mph | 0.3 | 1.7 | 3.4 | 10.3 | 27.4 | 51.4 | 102.9 |
| Arterial – 35 mph | 0.4 | 2.0 | 3.9 | 11.8 | 31.6 | 59.2 | 118.4 |
| | | | | | | | |
| **Data Collection Period = 180 minutes** | | | | | | | |
| Freeway – general use lanes | 0.1 | 0.3 | 0.7 | 2.0 | 5.5 | 10.2 | 20.5 |
| Freeway – HOV lanes | .04 | 0.2 | 0.4 | 1.3 | 3.6 | 6.7 | 13.3 |
| Arterial – 40 mph | 0.1 | 0.6 | 1.1 | 3.4 | 9.1 | 17.1 | 34.3 |
| Arterial – 35 mph | 0.1 | 0.7 | 1.3 | 3.9 | 10.5 | 19.7 | 39.5 |

## TABLE 3.5
## RURAL AREA DEFAULT TRAVEL TIME DATA COLLECTION RESOURCE REQUIREMENT ESTIMATES, EXPRESSED AS NUMBER OF DATA COLLECTION SESSIONS REQUIRED BY FACILITY TYPE

| **Facility Type & Duration of Data Collection Period** | **Number of Data Collection Sessions Required (Given Various Amounts of Study Area Mileage and Assuming One Data Collection Unit)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1 mi** | **5 mi** | **10 mi** | **30 mi** | **60 mi** | **150 mi** | **300 mi** |
| | | | | | | | |
| **Data Collection Period = 15 minutes** | | | | | | | |
| Freeway – general use lanes | .4 | 2.2 | 4.4 | 13.1 | 34.8 | 65.3 | 130.6 |
| Freeway – HOV lanes | .4 | 2.0 | 4.0 | 12.0 | 32.0 | 60.0 | 120.0 |
| Arterial – 40 mph | .7 | 3.3 | 6.5 | 19.6 | 52.2 | 97.9 | 195.9 |
| Arterial – 35 mph | .7 | 3.7 | 7.5 | 22.4 | 59.7 | 111.9 | 223.9 |
| | | | | | | | |
| **Data Collection Period = 30 minutes** | | | | | | | |
| Freeway – general use lanes | .2 | 1.1 | 2.2 | 6.5 | 17.4 | 32.6 | 65.3 |
| Freeway – HOV lanes | .2 | 1.0 | 2.0 | 6.0 | 16.0 | 30.0 | 60.0 |
| Arterial – 40 mph | .3 | 1.6 | 3.3 | 9.8 | 26.1 | 49.0 | 97.9 |
| Arterial – 35 mph | .4 | 1.9 | 1.9 | 5.6 | 14.9 | 28.0 | 56.0 |
| | | | | | | | |
| **Data Collection Period = 60 minutes** | | | | | | | |
| Freeway – general use lanes | .1 | 1.1 | 2.2 | 6.5 | 17.4 | 32.6 | 65.3 |
| Freeway – HOV lanes | .1 | .5 | 1.0 | 3.0 | 8.0 | 15.0 | 30.0 |
| Arterial – 40 mph | .2 | .8 | 1.6 | 4.9 | 13.1 | 24.5 | 49.0 |
| Arterial – 35 mph | .2 | .3 | .6 | 1.9 | 5.0 | 9.3 | 18.7 |
| | | | | | | | |
| **Data Collection Period = 180 minutes** | | | | | | | |
| Freeway – general use lanes | .1 | .5 | 1.1 | 3.3 | 8.7 | 16.3 | 32.6 |
| Freeway – HOV lanes | .03 | .2 | .3 | 1.0 | 2.7 | 5.0 | 10.0 |
| Arterial – 40 mph | .1 | .3 | .5 | 1.6 | 4.4 | 8.1 | 16.3 |
| Arterial – 35 mph | .1 | .3 | .6 | 1.9 | 5.0 | 9.3 | 18.7 |

## 3.3 Regional Resource Requirement Estimates

The default travel time data collection resource requirement estimates shown in Tables 3.4 and 3.5 were used to develop two sets of estimates to perform actual travel time data collection in the Central Puget Sound area. The first estimate was made for all interstates (urban and rural) and principle arterial roadways (urban and rural), and is shown in Table 3.6. This scenario includes a total of approximately 1,132 miles of roadway. The second estimate, shown in Table 3.7, was made for the much smaller set of roadways, all urban in nature, that are the subject of the field test portion of this project. This set of roadways totals approximately 205 miles.

For the regional set of roadways, values reflecting two 3-hour peak periods per day (i.e., two data collection sessions of 3 hours each per day) were used, the duration of the AM and PM peaks assumed by the Regional Council for regional traffic analysis. For the smaller set of roadways shown in Table 3.7, values reflect two 2-hour peak periods each day, the period selected for the purposes of this analysis. For both estimates, it was assumed that a single GPS data collection unit is available.

As shown in Table 3.6, over 178 days, or 59 weeks, of data collection are estimated to be necessary to collect the travel time data for the metropolitan transportation system (MTS), given the specified parameters (confidence level, number of GPS units available, etc.). The number of labor hours are equal to the number of days multiplied by 6 (two peak periods of 3 hours each).

Table 3.7 indicates that for the much smaller study area used in the field test portion of this project, approximately 47 days, or 16 weeks, of data collection are estimated to be required, again given the use of one GPS unit. ***It is important to note that this estimate does not include the additional time required to set-up for the next run, in cases where multiple runs are made during a single session, nor does it allow for errors, which will require some runs to be redone.***

## TABLE 3.6
## ESTIMATED NUMBER OF DATA COLLECTION SESSIONS (@ 2 3-HR SESSIONS/DAY) REQUIRED TO COLLECT REGIONAL TRAVEL TIME DATA
## (@ +/- 85% CONFIDENCE LEVEL AND +/- 5 MPH ALLOWABLE ERROR & w/1 GPS UNIT)

| **County/Facility Type** | **Centerline Miles** | **Facility Description** | **Number of Data Collection Sessions Needed Per Directional Mile (From Tables 3.4 & 3.5)** | **Estimated Number of Data Collection Sessions Needed (In Days)** | **Estimated Number of Data Collection Sessions Needed (In Weeks) *** |
|---|---|---|---|---|---|
| King | | | | | |
| Rural Interstate | 33.0 | Freeway - general use lanes | 0.036 | 2 | |
| Rural PA Other | 41.7 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 80.6 | Freeway - general use lanes | 0.068 | 11 | |
| Urban Principle Arterial - Freeway/Expressway | 105.7 | Freeway - general use lanes | 0.068 | | |
| Urban Principle Arterial - Other | 345.7 | Arterial - 40 mph | 0.114 | 79 | |
| Subtotal | 606.7 | | | 97 | 32 |
| Kitsap | | | | | |
| Rural Interstate | 0.0 | Freeway - general use lanes | 0.036 | 0 | |
| Rural PA Other | 39.8 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 0.0 | Freeway - general use lanes | 0.068 | 0 | |
| Urban Principle Arterial - Freeway/Expressway | 22.5 | Freeway - general use lanes | 0.068 | | |
| Urban Principle Arterial - Other | 39.2 | Arterial - 40 mph | 0.114 | 9 | |
| Subtotal | 101.5 | | | 13 | 4 |
| Pierce | | | | | |
| Rural Interstate | 3.4 | Freeway - general use lanes | 0.036 | 0 | |
| Rural PA Other | 4.2 | Arterial - 40 mph | 0.054 | 0 | |
| Urban Interstate | 22.7 | Freeway - general use lanes | 0.068 | 3 | |
| Urban Principle Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.068 | | |
| Urban Principle Arterial - Other | 175.7 | Arterial - 40 mph | 0.114 | 40 | |
| Subtotal | 237.8 | | | 44 | 15 |
| Snohomish | | | | | |
| Rural Interstate | 13.9 | Freeway - general use lanes | 0.036 | 1 | |
| Rural PA Other | 44.8 | Arterial - 40 mph | 0.054 | 5 | |
| Urban Interstate | 31.3 | Freeway - general use lanes | 0.068 | 4 | |
| Urban Principle Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.068 | | |
| Urban Principle Arterial - Other | 64.0 | Arterial - 40 mph | 0.114 | 15 | |
| Subtotal | 185.9 | | | 25 | 8 |
| Regional Totals | | | | | |
| Rural Interstate | 50.33 | Freeway - general use lanes | 0.036 | 4 | |
| Rural PA Other | 130.41 | Arterial - 40 mph | 0.054 | 14 | |
| Urban Interstate | 134.53 | Freeway - general use lanes | 0.068 | 18 | |
| Urban Principle Arterial - Freeway/Expressway | | Freeway - general use lanes | 0.068 | | |
| Urban Principle Arterial - Other | | Arterial - 40 mph | 0.114 | 0 | |
| **Total** | **1,131.9** | | | **178** | **59** |

*** Assumes data collection only on Tue, Wed and Thur**

## TABLE 3.7
## ESTIMATED NUMBER OF DATA COLLECTION SESSIONS (@ 2 2-HR SESSIONS/DAY) REQUIRED FOR STUDY CORRIDORS: USING DEFAULT VALUES
## (@ +/- 85% CONFIDENCE LEVEL AND +/- 5 MPH ALLOWABLE ERROR & w/1 GPS UNIT)

| **Corridor** | **Centerline Miles of Study Roadway** | **Number of Data Collection Sessions Needed Per Directional Mile Per 2-Hr Peak** | **Estimated Number of Data Collection Sessions Needed (In Days)** | **Estimated Number of Data Collection Sessions Needed (In Weeks) *** |
|---|---|---|---|---|
| 148th Ave SE/NE | 6.7 | 0.197 | 3 | 1 |
| I-5/Stewart SB-Olive NB/4th Ave | | | | |
| General Use Lanes | 27.6 | 0.102 | 6 | 2 |
| HOV Lanes | 22.8 | 0.067 | 3 | 1 |
| Subtotal | 50.4 | | 9 | 3 |
| I-90 | | | | |
| General Use Lanes | 13.8 | 0.102 | 3 | 1 |
| HOV Lanes | 6.6 | 0.067 | 1 | 0 |
| Subtotal | 20.4 | | 4 | 1 |
| I-405 | | | | |
| General Use Lanes | 14 | 0.102 | 3 | 1 |
| HOV Lanes | 26.8 | 0.067 | 4 | 1 |
| Subtotal | 40.8 | | 6 | 2 |
| SR 16/I-5 | 11.1 | 0.102 | 2 | 1 |
| SR 520 | 12.1 | 0.102 | 2 | 1 |
| SR 99 | 33.2 | 0.171 | 11 | 4 |
| SR 522 | 12.5 | 0.171 | 4 | 1 |
| SR 16/SR 3/SR 304 | 9.3 | 0.102 | 2 | 1 |
| SR 524 | 5.9 | 0.197 | 2 | 1 |
| S 180th St/SW 43rd St/Carr Rd SE | 2.4 | 0.197 | 1 | 0 |
| **Total** | **204.8** | | **47** | **16** |

*** Assumes data collection only on Tue, Wed and Thur**

**Note: mileage for some segments of I-5 HOV lanes, I-405 HOV lanes and SR 99 not available; total estimate will be in excess of what is shown in this table.**

# 4.0 FIELD TEST

This section describes the approach and the results of the field test of the proposed travel time data collection methodology. The results discussion begins with findings related to the methodology, including the equipment and data collection protocol and data reduction and manipulation approach. The travel time/speed data itself, including sample sizes, are then presented.

## 4.1 Approach

### Identification of Study Routes

Following a meeting of the Regional Council Congestion Management System (CMS) Subcommittee it was determined the corridors to be used in the travel time data collection field test would represent a subset of the Metropolitan Transportation System (MTS) facilities. It was also determined that most of the corridors should also be part of the CMS primary analysis network, with a limited number of non-CMS also included. In addition to these parameters, several additional selection considerations were added in order to insure that the proposed GPS data collection methodology and equipment was evaluated under a wide range of conditions. These considerations included selection of corridors located throughout the four county region, demonstrating a variety of roadway types and characteristics, and demonstrating a varied topography in the surrounding area.

The resulting list of field test corridors, developed by the Regional Council with input from the CMS Subcommittee, is shown in Table 4.1 and Figure 4-1. The total extent of the field test study corridors equals approximately 205 centerline miles.

## TABLE 4.1
## FIELD TEST STUDY CORRIDORS

| **Corridor/Facilities** | **From** | **To** | **Estimated Centerline Miles** |
|---|---|---|---|
| 148th Ave SE/NE | Redmond (SR 908) | to Bellevue (I-90) | 6.7 |
| I-5 / Stewart SB-Olive NB / 4th Ave (general use lanes and HOV lanes) | Downtown Everett (Pacific Ave) | Downtown Seattle (4th Ave and Pine St) | 50.4 |
| I-90 (general use lanes and HOV lanes) | Downtown Seattle (4th Ave SE) | Issaquah (Front St) | 20.4 |
| I-405 (general use lanes and HOV lanes) | Canyon Park (SR 527) | Downtown Bellevue (SE 8th St) | 40.8 |
| SR 16/I-5 | Gig Harbor (Pioneer Way) | Fife (SR 99) | 11.1 |
| SR 520 | I-5 | Redmond (SR 202) | 12.1 |
| SR 99 | Lynnwood (SR 524) | Federal Way (S 320th St) | 33.2 |
| SR 522 | I-5 | Woodinville (SR 202) | 12.5 |
| SR 16 / SR 3 / SR 304 | Port Orchard (SR 160) | Bremerton Ferry landing | 9.3 |
| SR 524 | Lynnwood (SR 99) | Canyon Park (SR 527) | 5.9 |
| S 180th St / SW 43rd St / Carr Rd SE | Tukwila (Southcenter Pkwy) | SR 515 | 2.4 |
| **Total** | | | **204.8** |

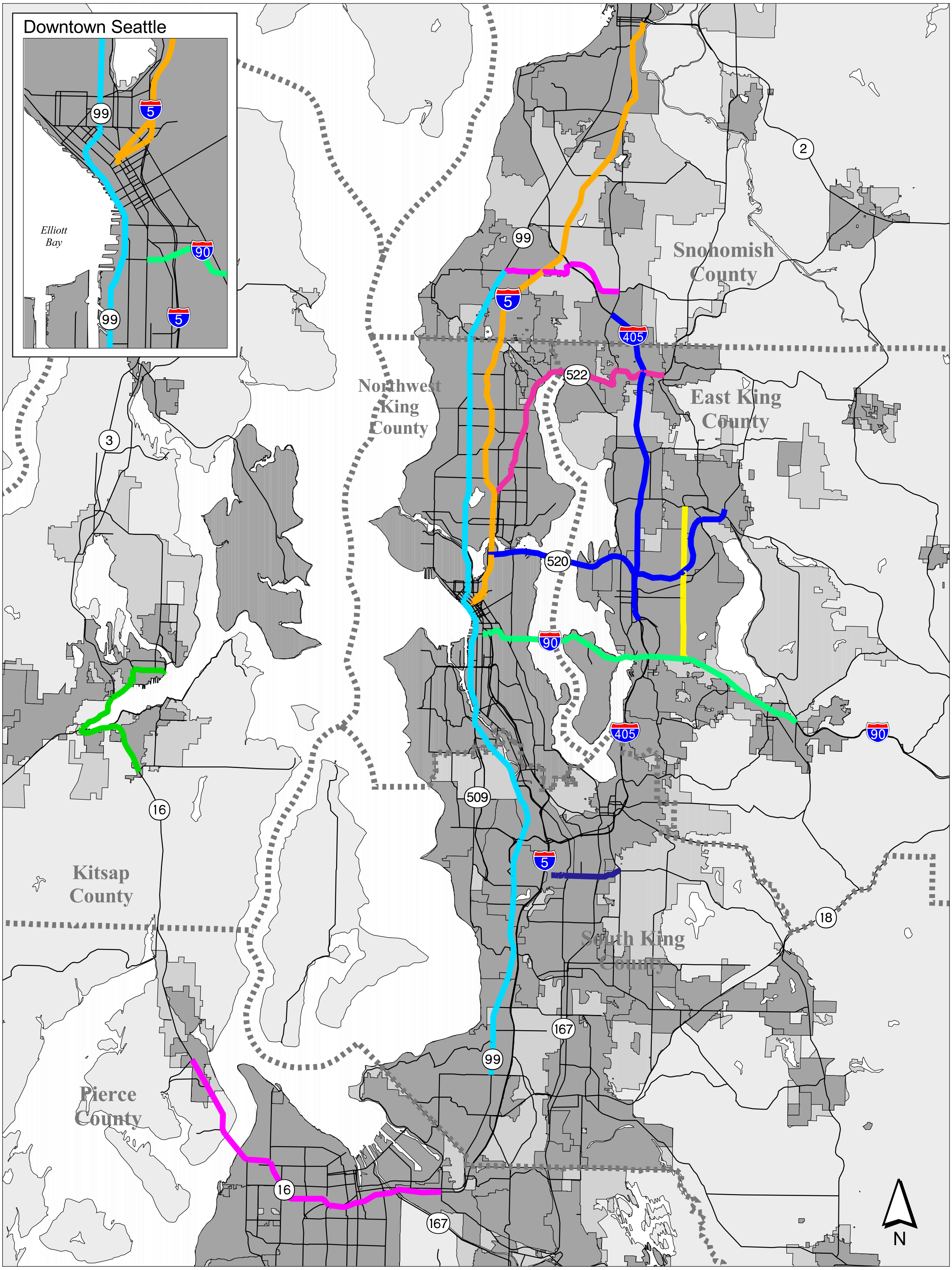


Figure 4-1 Fall 1999 Travel Time Data Collection Corridors

- 148th Ave: SR 908 to I-90
- I-5: Everett to Seattle
- I-90: Seattle to Issaquah
- I-405: Canyon Park to Bellevue
- SR 16/I-5 Gig Harbor to Fife
- SR 520: Seattle to Redmond
- SR 99: Federal Way to Lynnwood
- SR 522: I-5 to Woodinville
- SR 3/16: Port Orchard to Bremerton Ferry Landing
- SR 524: Lynnwood to Canyon Park
- S. 180th/43rd/Carr SE: Southcenter Pkwy to SR 515
- ▨ Incorporated Area
- ▨ 1999 Unincorporated Urban Growth Area
- CMS Subarea Boundary

4 0 4 Miles

X:\trans\staff\stephanier\GISprojects\CMSsubareas\GPSCorridorsjp.apr

## GPS Equipment

As explained in Section 2.1, the preferred GPS units, Trimble Placer 455DR's, could not be procured in time to use in the field test, given project schedule constraints. Instead, three substitute units, Trimble Pathfinder Pro's, were leased for the data collection effort. The Placer 455DR units have since been procured by the Regional Council and will be utilized for all future travel time data collection. The leased units were able to provide the same level of positional accuracy as the preferred units (and in fact can provide a better level of accuracy) but since they did not include dead reckoning devices, they were unusable in areas where the GPS satellite signal is obscured, such as in tunnels. This modification, though necessary in order to complete the project on time, did limit the amount of usable data that was collected, since there are GPS coverage gaps on the study corridors.

The GPS units utilized in the field test included the following components:

- Data logger to record and save position, speed and time data
- Battery pack with 3 batteries
- Battery charger
- Cables to connect the data logger to the batteries and to the personal computer into which data was downloaded from the logger
- Pathfinder Office 2.1 software package, required to view the data and to convert the data to standard database or spreadsheet formats
- GPS receiver

The installation of the GPS unit in the test vehicles was simple. The antenna for the GPS receiver was magnetically mounted to the roof and linked to the GPS receiver with a cable. A second cable connected the GPS unit to the data logger.

## Determination of Sample Sizes (Required Number of Runs Per Segment)

As explained in Section 1.0, the resources required to collect all of the desired travel time data were estimated prior to the field test, using the formulas and techniques presented in Section 3.3. As noted in Section 3.3***, the estimates do not include the additional time needed to get to and from the study routes nor the additional time needed due to errors and additional make-up runs***.

After it was determined that the project resources were far less than those required to collect all of the desired data, the objective of the field test was revised. Instead of collecting all of the required data for all corridors, it was decided that a minimum of two valid runs should be completed for each segment, so as to obtain observed values for the two key inputs to the resource requirement estimation formula: the average number of runs required by facility type and average travel speeds in the both directions of travel. Once the minimum two runs were completed for each corridor, remaining resources were to be spent collecting additional runs. This was the approach used in the field test.

## Data Collection Protocol

Personnel and Training and Procedures

A team of nine individuals collected the travel time data. The data collectors included engineers, university engineering students and engineering technicians. One individual was designated to do all of the data downloading from the data loggers into a personal computer.

The data collecting team was given hands-on training with the data collection units and completed test runs prior to the actual data collection. The training included written instructions for how to restart, name files, start/end file runs and recalibrate the units if they encountered system failure.

Each data collector was assigned one or more of the study corridors during each data collection session, which took place in the AM and PM peak periods. If the corridor was congested and the data collector was close to but not completely finished with a run when the peak period ended, they were instructed to complete the run. Data collectors were instructed to continue routes despite intermittent interruptions in satellite coverage.

Given the resources available for data collection, an expedient approach to corridor segmentation was utilized: the data collectors drove the entire length of the corridor in a single direction, then repeated the route in the opposite direction. Although required in order to collect all of the desired data, in future studies, consideration should be given to driving the corridors by segment. That is, breaking the corridor into smaller segments and driving both directions of each segment before moving on to the next segment. This method is more time-consuming, but depending on the purpose of the study and the traffic peaking characteristics along the various corridors, such an approach may be more appropriate. Dr. Cesar Quiroga of Texas Transportation Institute recommends segmentation into lengths that can be driven in 15 minutes (4). This approach has been utilized by KDD and Associates in other projects, after the field test, and has worked well.

During the data collection runs, the GPS units were set to record locations and times every 2 seconds. Originally, the GPS units were set to one second intervals, but the data files were very large. Two to three second intervals, with two being recommended, worked the best.

Timing of Data Collection

Travel time data was collected during the daily AM and PM peak periods, over the period October 19, 1999 to December 16, 1999, excluding the week of Thanksgiving and the week of the World Trade Organization Conference held. Data was collected only on Tuesdays, Wednesdays and Thursdays, so as to avoid the atypical traffic conditions common to Mondays, Fridays and Weekends. For the purposes of this study only, the

AM peak period was defined as 7 AM to 9 AM, and the PM peak period as 4 PM to 6 PM.

As noted in the discussions of sample size requirements and resource requirements in Section 2.0, the selection of the study time period has significant implications for the number of runs that will be required and the number of days of data collection that will be necessary. Assuming segment lengths are equal, longer study periods tend to produce runs with greater variation, thereby increasing the required sample size. Also, all other factors being equal, a longer study period allows more runs to be made each day, thus driving down the total time required to collect the data. The specification of the study period is also closely related to the purpose of the study. Longer study periods with more widely varying traffic characteristics are more appropriate to regional and/or planning studies, whereas shorter periods, with more homogenous traffic characteristics, are more appropriate to site specific and/or operations analysis.

## Data Reduction and Manipulation

Data was graphically viewed and cleaned, and converted into relational database files (Microsoft Access) using Pathfinder Office 2.1. Use of this software will not be necessary with the preferred GPS units (those that have been purchased and will be used for future studies). The database files were structured as recommended in the methodology outlined in Section 2.2 and included latitude, longitude, speed and time.

The relational database files with the raw data were provided to the Regional Council, where the additional processing necessary to calculate basic results, such as travel time, was performed. The first step in the Regional Council’s processing effort consisted of segmenting the travel time run data, which was collected for entire corridors. Many of the travel time runs were quite long and it was determined that segmentation would be appropriate. Note that the segmentation occurred after the travel time data collection runs were made, which typically consisted of a single data collection team driving the entire length of a corridor in one direction, then turning around and driving the entire corridor in the other direction. Segmentation was based primarily upon major cross streets, although the actual beginning and end points for each corridor and segment were dictated by the availability of usable travel time data. The end points that were dictated by data availability are not exactly the same as those shown in Table 4.1. Data availability was primarily limited by loss of satellites due to tunnels, overpasses, etc. and would not be a problem with the Placer 455DR using dead reckoning. In Section 4.2, all results are reported for the defacto segments that were established based on data availability (see Table 4.2).

After segmenting the data files, the Regional Council performed the following steps to calculate travel times for each run:

- Using custom macros written in Visual Basic for Applications, the individual data files for each travel time run were merged into a single Microsoft Access database. A second table was created that contained the characteristics of each travel time run, including direction, peak period, lane type, run file name and corridor name.

- Data was summarized using a variety of database queries.

- An Avenue script was developed in ArcView that allowed querying of a particular corridor in the Access database using an SQL connect. The tool allowed tolerances to be specified and geocoding of two points along the corridor. The tool then calculated the travel time between the two points for each run and reported the results in .dbf files.

The .dbf files that contained the results of each individual travel time run, including travel times and segment lengths, were provided to the consulting team for use in subsequent reporting and analysis. As noted previously, project resources prevented the use of GIS for this subsequent work, and the effort was accomplished using the Microsoft Access database and Microsoft Excel spreadsheet software. The results are reported in Section 4.2 in tabular form.

## 4.2 Results

### Equipment and Procedures

Overall, the GPS equipment performed reasonably well and the data collection procedures that were utilized were effective.

Equipment Performance

Two equipment difficulties were encountered. The batteries that were provided by the manufacturer were supposed to be able to record information for at least 6 hours before being recharged. Unfortunately, one of the batteries continually failed during data collection runs, even if it was recharged for several hours prior. This resulted in several lost data sets. The other equipment problem pertained to reconfiguration of the data loggers. Even though the same individual reset the data loggers each time, some of the settings did not activate correctly. This resulted in data files being produced that lacked certain key variables (for example, speed information), that rendered the files unusable.

Neither of these difficulties should be encountered in the future using the Placer 455DR units that the Regional Council has acquired. The Placer units utilize a 12-V DC power supply (e.g., the vehicle battery, accessed via a cigarette lighter adapter), and failures are rare. Also, the Placer units do not require any configuration resetting. Further, since the Placer units produce a standard NMEA output, it is possible to write a simple piece of code (e.g. in Visual Basic) to drive the data collection without ever having to reset the units. New technologies now make it possible to even use Pocket PC (i.e., Windows CE) devices that replace laptop computers completely, making the data collection even simpler.

### Data Gaps Caused by GPS Satellite Repositioning

Unrelated to the GPS data collection units themselves, additional problems and data gaps were encountered due to changes in the orbits of the government GPS satellites. These changes, which are relatively infrequent, resulted in a number of data gaps and rendered some runs invalid. As noted in Section 6.0, it is recommended that the US Coast Guard be consulted during the planning of future travel time data collection efforts in order to anticipate such difficulties. The Coast Guard maintains a web site that can be consulted (www.navcen.uscg.mil), or the local offices can be contacted directly. Failure to consult the Coast Guard in advance of the field test was an oversight.

### Data Loss Due to Lack of GPS Coverage

As noted in Sections 2.1 and 4.1, due to delays in procuring the preferred GPS units, substitute units were leased. These units did not include the dead reckoning (DR) devices that can be used to estimate locations in areas where the GPS satellite signal is blocked by tall buildings, overpasses or in tunnels. As a result, a number of runs contained small data gaps. Generally, small data gaps are not problematic, and this issue will not be a concern with the units that have been purchased by the Regional Council and that will be used for future data collection.

### Personnel Compliance with Data Collection Protocol

For the most part the data collection personnel complied with the data collection protocol. However, some errors and inconsistencies occurred, including failure to note, or inconsistency in the way the cause of major delays were noted, failure to activate the GPS unit at the appropriate times and locations, and inconsistencies and resulting confusion associated with file names. Some of these difficulties resulted due to the failure to specify procedures in advance and to adequately train the data collection staff. Recommendations in these areas are presented in Section 5.0.

### Overall Data Collection Success Rate

Despite the occurrence of the various data collection problems noted above, the overall data collection success rate was favorable, approximately 89%, meaning that on average, 9 out of 10 runs produced complete and usable data files. Of the approximately 10% loss rate, less than 3% was due to strictly operator error. As discussed further in Section 5.0, it is expected that this overall data collection success rate is approximately equal to the rate obtained using manual methods. With the elimination of errors due to factors beyond the control of the data collectors and/or that will not occur with the preferred GPS units, and after training procedures are fine-tuned, it is expected that the error rate will be less than that found with traditional manual test care techniques.

Total Resources Required

The total in-field resources required to conduct the field test (i.e., excluding data reduction and manipulation) amounted to approximately 250 person-hours, spread out over approximately 7 weeks. Given the three-days-per-week data collection strategy, this results in an average of approximately 12 hours of in-field effort per data collection day. This is far more than the 4 hours that theoretically would be required for the actual travel time runs (the 2 hours in the AM and 2 hours in the PM peak periods). Some of the additional time is for driving to and from the study area. Comparisons between actual and estimated resource requirements are discussed further in Sections 5.0 and 6.0.

## Travel Time/Speed Results

Table 4.2 presents the travel time data that was collected in the field test, focusing on the factors that are most significant in estimating the resources required to perform travel time studies: the number of valid runs completed, the observed range of speeds, the number of runs required to achieve various levels of statistical validity and generalizability (i.e., confidence levels and allowable error) and the number of remaining runs that must be performed. Results are presented according to the segmentation scheme that was developed during data reduction, in which data availability dictated specific termini. A more detailed summary of the results, including individual segment lengths, run dates, travel times, speeds, and data file names is included in Appendix B. The discussion that follows summarizes the information contained in Table 4.2, beginning with an overall status of the data collection effort, including the number of valid runs completed and the number of additional runs required.

Project resources did not allow for mapping of the travel time results. However, the Regional Council developed Figure 4-2 as a sample of one type of map that can be produced, a color-coded travel speed map.

Summary of Valid Runs Completed and Additional Runs Required

Table 4.3 summarizes the number of valid runs completed and additional runs required for each of the four types of roadway facilities included in the Regional Council travel time study: general-use freeway lanes, HOV freeway lanes, 40 mph arterial streets and 35-mph arterial streets. Invalid runs, those that included data recording errors or other fatal flaws, have been removed from the travel time results database.

As explained in Section 3.0, it was determined that study resources were insufficient to collect complete travel time information for all of the study corridors and segments and that the goal should instead be to collect at least two runs per route. (A “route” describes a given segment, in a given direction, during a given peak period, whereas a “run” refers to an actual data collection trip along a given route).

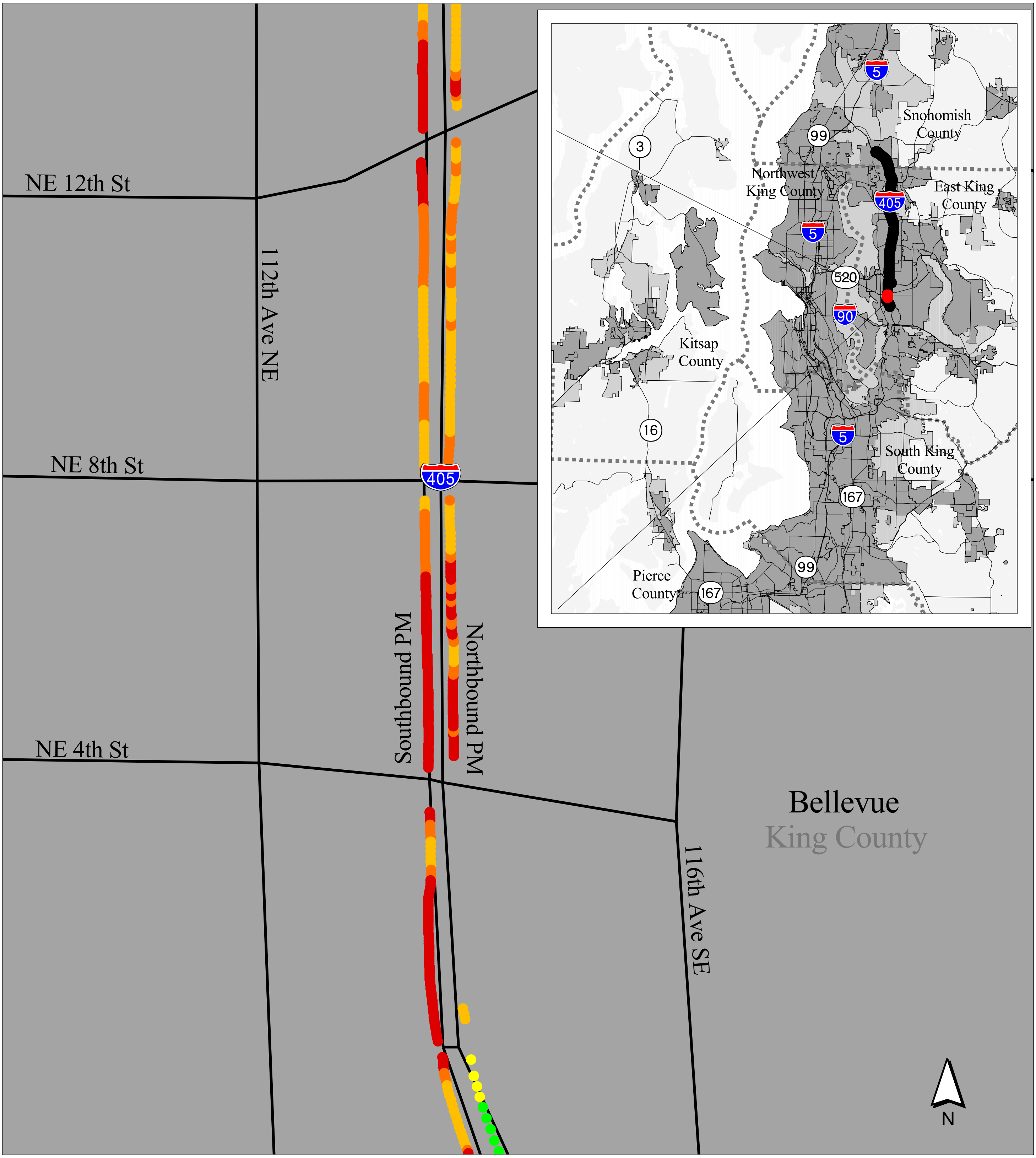


Figure 4-2 Sample Northbound & Southbound Speeds on I-405 in Downtown Bellevue

Travel Speeds

● 0-10 MPH

● 10-15 MPH

● 15-25 MPH

● 25-35 MPH

● 35-70 MPH

▨ Incorporated Area

▨ 1999 Unincorporated Urban Growth Area

CMS Subarea Boundry

Metropolitan Transportation System (MTS)

400 0 400 Feet

W:\GIS\Projects\ldtd\cms\cms405.apr

## TABLE 4.2
## CALCULATION OF REQUIRED RUNS

| Corridor | Segment | Facility Type | Peak Period | Dir | Speed Range (mph) | # of Valid Runs Completed | Total Required # of Runs At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | | Additional # of Runs Required At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 95% | 85% | 75% | 95% | 85% | 75% |
| 148 Ave. SE | I-90 to Redmond Rd | Arterial | AM | NB | 15 | 2 | 8 | 6 | 5 | 6 | 4 | 3 |
| | | | PM | NB | 8 | 2 | 5 | 4 | 3 | 3 | 2 | 1 |
| | | | AM | SB | 13 | 2 | 7 | 5 | 4 | 5 | 3 | 2 |
| | | | PM | SB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | Redmond Rd to Redmond Way | Arterial | AM | NB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| I-405 | SE 8th Street to SR 520 | Freeway - general lanes | AM | NB | 42 | 2 | >15 | >10 | >8 | ≥ 13 | ≥ 8 | ≥ 6 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 18 | 2 | 9 | 6 | 5 | 7 | 4 | 3 |
| | | | PM | SB | 19 | 2 | 9 | 7 | 5 | 7 | 5 | 3 |
| | SR 520 to NE 85th St | Freeway - general lanes | AM | NB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | AM | SB | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| | | | PM | NB | 48 | 3 | >15 | >10 | >8 | ≥ 12 | ≥ 7 | ≥ 5 |
| | | | PM | SB | 26 | 3 | 12 | 9 | 7 | 9 | 6 | 4 |
| | NE 85th St to SR 522 | Freeway - general lanes | AM | NB | 7 | 2 | 5 | 4 | 3 | 3 | 2 | 1 |
| | | | AM | SB | 10 | 2 | 6 | 4 | 4 | 4 | 2 | 2 |
| | | | PM | NB | 22 | 3 | 9 | 7 | 6 | 6 | 4 | 3 |
| | | | PM | SB | 2 | 3 | 2 | 2 | 2 | 0 | 0 | 0 |
| | SR 522 to SR 524 | Freeway - general lanes | AM | NB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | AM | SB | 10 | 2 | 6 | 4 | 4 | 4 | 2 | 2 |
| | | | PM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | 27 | 3 | 15 | 10 | 8 | 12 | 7 | 5 |
| I-5 | Pacific Ave to 128th St SE | Freeway - general lanes | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | | | PM | SB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | 128th St to 204th St | Freeway - general lanes | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | NB | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | 204th St to N 145th St | Freeway - general lanes | AM | NB | 18 | 2 | 9 | 6 | 5 | 7 | 4 | 3 |
| | | | AM | SB | 46 | 2 | >15 | >10 | >8 | ≥ 13 | ≥ 8 | ≥ 6 |
| | | | PM | NB | 27 | 1 | 15 | 10 | 8 | 14 | 9 | 7 |
| | | | PM | SB | 22 | 2 | 8 | 7 | 6 | 6 | 5 | 4 |
| | 204th St to N 145th St | Freeway - HOV lanes | AM | NB | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| | | | AM | SB | 23 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |
| | | | PM | NB | 23 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |
| | | | PM | SB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | N 145th St to N 45 St | Freeway - general lanes | AM | NB | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | AM | SB | 14 | 2 | 7 | 5 | 4 | 5 | 3 | 2 |
| | | | PM | NB | 12 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | PM | SB | 25 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |

Shaded areas show where the required number of runs have been completed to acheive the given confidence level

## TABLE 4.2
## CALCULATION OF REQUIRED RUNS

| Corridor | Segment | Facility Type | Peak Period | Dir | Speed Range (mph) | # of Valid Runs Completed | Total Required # of Runs At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | | Additional # of Runs Required At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 95% | 85% | 75% | 95% | 85% | 75% |
| | N 45th St to Denny Way | Freeway - general lanes | AM | NB | 37 | 2 | >15 | >10 | >8 | ≥ 13 | ≥ 8 | ≥ 6 |
| | | | AM | SB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | PM | NB | 25 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |
| | | | PM | SB | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| | NE Northgate Way to I-405 | Freeway - HOV lanes | AM | NB | 0 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 16 | 2 | 8 | 6 | 5 | 6 | 4 | 3 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | I-405 to SR 526 | Freeway - HOV lanes | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | NB | 12 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | PM | SB | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| I-90 | Rainier Ave S to I-405 | Freeway - general lanes | AM | EB | 16 | 2 | 8 | 6 | 5 | 6 | 4 | 3 |
| | | | AM | WB | 10 | 2 | 6 | 4 | 4 | 4 | 2 | 2 |
| | | | PM | EB | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | PM | WB | 25 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |
| | I-405 to Front Street | Freeway - general lanes | AM | EB | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | AM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | EB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | PM | WB | 21 | 2 | 10 | 7 | 6 | 8 | 5 | 4 |
| | Bellevue Way SE to NW Sammamish | Freeway - HOV lanes | AM | EB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | WB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | EB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | WB | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| S 180th St/ SW 43rd St/ Carr Rd SE | W Valley Rd to 108th Ave SE | Arterial | AM | EB | 12 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | AM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | EB | 1 | 3 | 3 | 2 | 2 | 0 | 0 | 0 |
| | | | PM | WB | 6 | 3 | 4 | 3 | 3 | 1 | 0 | 0 |
| SR 3/SR 16 | Pacific Ave to Sedgewick Rd | Arterial | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 6 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| SR 16/I-5 | Wollochet Dr. NW to 12th St | Freeway - general lanes | AM | NB | 31 | 3 | 15 | 10 | 8 | 12 | 7 | 5 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 11 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | 12th St to SR 99 | Freeway - general lanes | AM | NB | 24 | 2 | 12 | 9 | 7 | 10 | 7 | 5 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | 21 | 2 | 10 | 7 | 6 | 8 | 5 | 4 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| SR 520 | Montlake to Bellevue Way | Freeway - general lanes | AM | EB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | WB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | EB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | WB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | Bellevue Way to East of I-405 | Freeway - general lanes | AM | EB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | AM | WB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | EB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |

Shaded areas show where the required number of runs have been completed to acheive the given confidence level

## TABLE 4.2
## CALCULATION OF REQUIRED RUNS

| Corridor | Segment | Facility Type | Peak Period | Dir | Speed Range (mph) | # of Valid Runs Completed | Total Required # of Runs At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | | Additional # of Runs Required At Varying Confidence Levels (Allowable Error = +/- 5 mph) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 95% | 85% | 75% | 95% | 85% | 75% |
| | East of I-405 to SR 202 | Freeway - general lanes | AM | EB | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | AM | WM | | 0 | No valid runs completed | | | ≥ 2 | ≥ 2 | ≥ 2 |
| | | | PM | EB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| SR 522 | I-5 Ramp to 68th St | Arterial | AM | EB | 9 | 3 | 5 | 4 | 3 | 2 | 1 | 0 |
| | | | AM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | EB | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | | | PM | WB | 11 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | 68th St to SR 202 | Arterial | AM | NB | 7 | 2 | 5 | 4 | 3 | 3 | 2 | 1 |
| | | | AM | SB | 13 | 2 | 7 | 5 | 4 | 5 | 3 | 2 |
| | | | PM | EB | 30 | 3 | 15 | 10 | 8 | 12 | 7 | 5 |
| | | | PM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| SR 524 | SR 99 to SR 527 SE | Arterial | AM | EB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | WB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | EB | 10 | 4 | 6 | 4 | 4 | 2 | 0 | 0 |
| | | | PM | WB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| SR 99 | Battery St. to 45th St. | Arterial | AM | NB | | 0 | No valid runs completed | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | 0 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | | | PM | NB | | 0 | No valid runs completed | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | 31 | 2 | 15 | 10 | 8 | 13 | 8 | 6 |
| | 45th St. to 105th St. | Arterial | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | 12 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | PM | NB | | 0 | No valid runs completed | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | 11 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | 105th St to SR 524 | Arterial | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | PM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | Alaskan Viaduct to E Marginal Way | Arterial | AM | NB | 3 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | AM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | E Marginal Way to S 188th St | Arterial | AM | NB | 16 | 3 | 8 | 6 | 5 | 5 | 3 | 2 |
| | | | AM | SB | 11 | 2 | 6 | 5 | 4 | 4 | 3 | 2 |
| | | | PM | NB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | SB | 1 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | S 188th St to Kent Des Moines Rd | Arterial | AM | NB | 24 | 4 | 12 | 9 | 7 | 8 | 5 | 3 |
| | | | AM | SB | 21 | 2 | 10 | 7 | 6 | 8 | 5 | 4 |
| | | | PM | NB | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 0 |
| | | | PM | SB | 6 | 3 | 4 | 3 | 3 | 1 | 0 | 0 |
| | Kent Des Moines Rd to S 320th St | Arterial | AM | NB | 20 | 4 | 10 | 7 | 6 | 6 | 3 | 2 |
| | | | AM | SB | 14 | 2 | 7 | 5 | 4 | 5 | 3 | 2 |
| | | | PM | NB | 6 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | SB | 6 | 3 | 4 | 3 | 3 | 1 | 0 | 0 |
| I-405 | I-5 to I-90 | Freeway - HOV lanes | AM | NB | 17 | 2 | 8 | 6 | 5 | 6 | 4 | 3 |
| | | | AM | SB | 4 | 2 | 4 | 3 | 3 | 2 | 1 | 1 |
| | | | PM | NB | 10 | 3 | 6 | 4 | 4 | 3 | 1 | 1 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | I-90 to SR 520 | Freeway - HOV lanes | AM | NB | 0 | 2 | 3 | 2 | 2 | 1 | 0 | 0 |
| | | | AM | SB | 3 | 3 | 3 | 3 | 2 | 0 | 0 | 0 |
| | | | PM | NB | 4 | 3 | 4 | 3 | 3 | 1 | 0 | 0 |
| | | | PM | SB | 5 | 3 | 4 | 3 | 3 | 1 | 0 | 0 |
| | SR 520 to SR 527 | Freeway - HOV lanes | AM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | AM | SB | 7 | 2 | 5 | 4 | 3 | 3 | 2 | 1 |
| | | | PM | NB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |
| | | | PM | SB | | 1 | Only have 1 run - can't compute range | | | ≥ 1 | ≥ 1 | ≥ 1 |

Shaded areas show where the required number of runs have been completed to acheive the given confidence level

Table 4.3 indicates that a total of 251 valid runs were obtained, spread relatively evenly over the AM and PM peak periods. Table 4.3 also estimates how many additional runs must be made in order to achieve various levels of statistical confidence. ***Depending on the level of confidence required, the 251 runs that were completed in the field test account for between 26% and 40% of the total required runs.***

### Break-Down of Valid Runs and Achieved Statistical Confidence Levels

Table 4.4 summarizes the extent of data collection that was achieved in the field test in terms of the number of valid runs completed on the various individual study routes. As shown in Table 4.4, given the study corridors and segments, there are a total of 148 separate routes (37 segments x 2 directions x 2 peak periods = 148***). As indicated, at least two valid travel time runs—the minimum goal—were obtained for exactly half (74) of the 148 routes .***

### TABLE 4-3
### SUMMARY OF VALID RUNS COMPLETED AND REMAINING RUNS REQUIRED

| | Valid Runs and Remaining Runs Required at Various Confidence Levels (assuming +/- 5 mph allowable error) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AM | | | | PM | | | | Total | | | |
| | | Remaining | | | | Remaining | | | | Remaining | | |
| **Facility Type** | **Done** | **95%** | **85%** | **75%** | **Done** | **95%** | **85%** | **75%** | **Done** | **95%** | **85%** | **75%** |
| Freeway – general purpose lanes | 45 | 199 | 132 | 101 | 55 | 202 | 137 | 101 | 100 | 401 | 269 | 202 |
| Freeway – HOV lanes | 23 | 44 | 35 | 26 | 25 | 49 | 37 | 27 | 48 | 93 | 72 | 53 |
| Arterial – 40 mph | 38 | 95 | 68 | 48 | 34 | 88 | 61 | 47 | 72 | 183 | 129 | 95 |
| Arterial – 35 mph | 12 | 36 | 27 | 19 | 19 | 15 | 9 | 5 | 31 | 51 | 36 | 24 |
| **Total** | **118** | **374** | **262** | **194** | **133** | **354** | **244** | **180** | **251** | **728** | **506** | **374** |

### TABLE 4.4
### SUMMARY OF NUMBER OF VALID RUNS COMPLETED

| | Number of Valid Runs Completed | Number of Study Routes |
|---|---|---|
| | 0 | 14 |
| | 1 | 40 |
| | 2 | 74 |
| | 3 | 17 |
| | 4 | 3 |
| **Total** | 251 | 148 |

Table 4.5 identifies the number of study routes where various levels of statistical confidence were reached, given the number of valid travel runs that were obtained. ***Confidence levels of 75% or better were achieved on 61, or about 41%, of the 148 study routes.***

### TABLE 4.5
### NUMBER OF ROUTES BY LEVEL OF CONFIDENCE ACHIEVED

| | | | | | Number of Routes with Sufficient Runs to Achieve Level of Confidence (at +/- 5 mph error) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Facility Type** | **# of Corridors** | **# of Segments** | **# of Routes** | **# of Valid Runs** | **95%** | **85%** | **75%** | **<75%** | **Total** |
| Freeway – general lanes | 5 | 16 | 64 | 100 | 3 | 5 | 11 | 45 | 64 |
| Freeway – HOV lanes | 3 | 7 | 28 | 48 | 3 | 7 | 8 | 10 | 28 |
| Arterial – 40 mph | 3 | 10 | 40 | 72 | 0 | 5 | 9 | 26 | 40 |
| Arterial – 35 mph | 3 | 4 | 16 | 31 | 1 | 3 | 6 | 6 | 16 |
| **Total** | **14** | **37** | **148** | **251** | **7** | **20** | **34** | **87** | **148** |

Observed Speeds

Tables 4.6 summarizes the observed total travel speeds—reflecting both stopped delay and running time—by facility type, peak period, and by directionality (in terms of peak or off-peak, with "peak" referring to the predominant direction for the given time period in question). Table 4.7 summarizes the same information in a slightly different manner: the relationship between peak and off-peak direction speeds to the posted speed limit. The following observations are based on Tables 4.6 and 4.7:

- Logically, in all cases average speeds were higher in the off-peak direction, and significantly higher on the HOV freeway lanes than on the general use freeway lanes.
- In the peak flow direction, observed speeds on the general use facilities averaged between 54% and 60% of the posted speed, compared to the HOV freeway lanes where peak direction speeds averaged 65% of the posted speed.
- Overall, peak direction speeds were lower in the PM period than in the AM period. In terms of specific facility types, all facilities demonstrated this pattern except general-use lane freeways, where the average speed was slightly higher in the PM.
- Freeway segments showed significantly larger differentials between average speeds in the peak and off-peak directions than did the arterial segments (between 40 and 50% differences for freeways and between 17 and 20% for arterials).

**TABLE 4.6**
**SUMMARY OF OBSERVED AVERAGE SPEEDS BY FACILITY TYPE**

| | **Observed Average Speeds (mph)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **AM** | | | **PM** | | | **Overall** | | |
| **Facility Type** | **PK** | **OPK** | **Overall** | **PK** | **OPK** | **Overall** | **PK** | **OPK** | **Overall** |
| Freeway – general lanes | 33 | 47 | 39 | 35 | 48 | 41 | 34 | 47 | 40 |
| Freeway – HOV lanes | 40 | 56 | 48 | 38 | 54 | 46 | 39 | 55 | 47 |
| Arterial – 40 mph | 25 | 31 | 28 | 22 | 24 | 23 | 24 | 28 | 26 |
| Arterial – 35 mph | 23 | 25 | 24 | 18 | 22 | 19 | 19 | 24 | 21 |
| **All Facilities** | **29** | **41** | **35** | **29** | **40** | **34** | **29** | **41** | **34** |

**PK** = Peak traffic direction, i.e., the direction with more than 50% of the total two-way traffic volume.
**OPK** = Off-peak traffic direction, i.e., the direction with less than 50% of the total two-way traffic volume.

### TABLE 4.7
### RELATIONSHIP BETWEEN OBSERVED AVERAGE TRAVEL SPEEDS AND POSTED SPEEDS

| Facility Type | Difference Between Average Observed Speeds and Posted Speeds (mph) | | | | | |
|---|---|---|---|---|---|---|
| | AM | | PM | | Overall | |
| | Peak Direction | Off-Peak Direction | Peak Direction | Off-Peak Direction | Peak Direction | Off-Peak Direction |
| Freeway – general lanes | -27.3 | -13.3 | -24.8 | -12.2 | -25.5 | -12.7 |
| Freeway – HOV lanes | -19.7 | -3.8 | -22.0 | -6.3 | -20.9 | -5.0 |
| Arterial – 40 mph | -14.9 | -9.4 | -17.8 | -15.7 | -16.4 | -12.0 |
| Arterial – 35 mph | -12.4 | -10.0 | -17.2 | -13.0 | -15.6 | -11.5 |
| **Overall** | **-20.5** | **-10.1** | **-21.1** | **-12.1** | **-20.8** | **-11.1** |

Table 4.8 summarizes the average ranges of observed travel speeds by facility type, peak period and directionality. The speed range consists of the variability between the highest and lowest travel speeds obtained over multiple runs on a given route. The following observations are based on the data shown in Table 4.8:

- Overall, the average speed ranges are fairly high, reflecting considerable variability in travel conditions, which increases the required number of runs in order to achieve statistical confidence.

- Overall—considering both the AM and PM peak periods and both the peak and off-peak directions, the variability in observed travel speeds is very similar for general-use lane freeway, 40-mph arterial and 35-mph arterial segments, all of which demonstrated average speed ranges between 11 and 16 mph. Variability was much less on the HOV-lane freeway routes, with an overall average speed range of about 6 mph.

- The variability in travel speeds was at least equal to, and in most cases was higher in the peak direction, although the differences, averaged across all four facility types are small (1 mph in either peak). The least difference between peak and off-peak direction variability was observed on the general-use freeway lane routes, although in absolute terms, these routes exhibited the greatest variability (in both peak and off-peak directions).

### TABLE 4.8
### SUMMARY OF OBSERVED AVERAGE SPEED RANGES BY FACILITY TYPE

| Facility Type | Observed Average Speed Ranges (mph) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | AM | | | PM | | | Overall | | |
| | PK | OPK | Overall | PK | OPK | Overall | PK | OPK | Overall |
| Freeway – general lanes | 16 | 16 | 16 | 16 | 17 | 16 | 16 | 16 | 16 |
| Freeway – HOV lanes | 4 | 6 | 5 | 10 | 3 | 7 | 7 | 5 | 6 |
| Arterial – 40 mph | 15 | 9 | 12 | 11 | 6 | 9 | 13 | 8 | 11 |
| Arterial – 35 mph | 12 | 10 | 11 | 17 | 13 | 16 | 16 | 12 | 14 |
| **All Facilities** | 13 | 11 | 12 | 12 | 11 | 12 | 13 | 11 | 12 |

**PK** = Peak traffic direction, i.e., the direction with more than 50% of the total two-way traffic volume.
**OPK** = Off-peak traffic direction, i.e., the direction with less than 50% of the total two-way traffic volume.

### Data for Refinement of Planning-Level Estimates and Regional Council Area-Wide Estimates

This section focuses on the observed values for the two key variables in the resource requirements estimates that were presented in Section 3.0 that were previously estimated, but that will be updated using the results of the field test: the ***average number of runs*** required to achieve varying levels of statistical confidence (a direct reflection of the variability in travel speeds observed across multiple runs) and the relationship between ***average speeds in the peak and off-peak flow directions*** (a key determinant of how much mileage can be covered per session by each data collection unit).

The other key influence on resource requirements noted in Section 3.0, the duration of the peak period (which, along with speeds plays a major role in determining the duration of the data collection window during each peak period) is not addressed. As noted in Section 5.0, additional analysis of the raw travel time data would be useful in helping to determine how much of the observed variability in travel times may have resulted from the length of the study period. A data collection period that is overly long, where traffic conditions vary considerably within a single "peak period", exaggerates the variability in travel speeds and therefore increases the number of runs required.

#### *Average Number of Required Runs*

Table 4.9 identifies, based on the field test data, the average total number of runs required by facility type, by peak period, and by confidence level. The results of the field test support the general rule-of-thumb estimate of between 3 and 5 runs per route, assuming 75 to 85% confidence level with +/- 5 mph of error. The results also generally validate the assumption of 4 required runs used in the default resource requirement estimates developed in Section 3.2, although it is clear that between one less, and four additional runs may be necessary depending on the facility type, confidence level and peak period.

#### *Peak and Off-Peak Direction Speed Relationships*

Table 4.10 identifies, based on the field test results summarized in Tables 4.6 and 4.7, the average relationship between speeds in the peak and off-peak directions, by facility type. These speeds are key inputs to the resource requirements estimation formula. The results in Table 4.10 indicate that observed values are in many cases, significantly different than the estimated values used in the resource requirements estimation formula. Specifically:

- Observed off-peak direction speeds for are significantly lower than the assumed values—between 5 and 8 miles per hour lower.

## TABLE 4.9
## AVERAGE TOTAL NUMBER OF RUNS REQUIRED BY FACILITY TYPE – BASED ON FIELD TEST RESULTS

| | **Average Number of Runs Required at Various Confidence Levels (assuming allowable error of +/- 5 mph)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **95%** | | | **85%** | | | **75%** | | |
| **Facility Type** | **AM** | **PM** | **Overall** | **AM** | **PM** | **Overall** | **AM** | **PM** | **Overall** |
| Freeway – general lanes | 6 | 8 | 7 | 5 | 6 | 5 | 4 | 5 | 4 |
| Freeway – HOV lanes | 5 | 6 | 5 | 4 | 4 | 4 | 3 | 4 | 3 |
| Arterial – 40 mph | 7 | 6 | 6 | 5 | 4 | 5 | 4 | 4 | 4 |
| Arterial – 35 mph | 6 | 4 | 5 | 5 | 3 | 4 | 4 | 3 | 3 |
| **All Facilities** | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 4 | 4 |

## TABLE 4.10
## SUMMARY OF OBSERVED AVERAGE SPEEDS BY FACILITY TYPE

| **Facility Type** | **Posted Speed (mph)** | **Average Off-Peak Direction Speed (mph)** | **Average Peak Direction Speed (as fraction of Off-Peak Speed)** |
|---|---|---|---|
| Freeway – general lanes | 60 | 47 | .72 |
| Freeway – HOV lanes | 60 | 55 | .71 |
| Arterial – 40 mph | 40 | 28 | .86 |
| Arterial – 35 mph | 35 | 24 | .79 |

Peak traffic direction = the direction with more than 50% of the total two-way traffic volume.
Off-peak traffic direction = the direction with less than 50% of the total two-way traffic volume.

- Observed peak direction speeds, expressed as percentages of the off-peak speeds, are significantly higher for the general use facilities than the assumed values—between 17 and 36 percentage points higher. The speed for the HOV facilities is significantly lower than the assumed percentage, which was assumed to be equal to the off-peak direction speed.

The next section of this report utilizes the information in Tables 4.9 and 4.10 to refine the initial, or default, planning level travel time data collection resource requirement estimates presented in Section 3.0.

# 5.0 REFINED RESOURCE REQUIREMENTS ESTIMATES

## 5.1 Facility Type-Specific Estimates

Tables 5.1 through 5.3 present the refined, Central Puget Sound area-specific versions of the urban area resource requirement estimates shown in Table 3.4 in Section 3.2. The rural area default estimates could not be refined since all of the field test study corridors were urban in nature.

The default assumptions regarding the number of required runs and the relationship between peak and off-peak direction speeds were updated using the results of the field test (the results shown in Tables 4.8 and 4.9). The refined estimates were calculated using the same formulas presented in Section 3.1, but have utilized the updated values.

The three tables, Table 5.1 through 5.3, correspond to three different levels of confidence: 95%, 85% and 75%. The results have been presented for different confidence levels so that the Regional Council can utilize different estimates depending on the specific purposes of future travel time data collection efforts. As discussed earlier, there is a trade-off between level of confidence and the resources required to collect the data. For planning and/or regional level analyses a confidence level of 75% or 85% may be satisfactory, whereas a higher confidence level is typically preferred for site specific and/or operations analyses. In all cases, the results in Tables 5.1 through 5.3 reflect an allowable level of error of +/- 5 mph, the maximum level of error typically recommended for planning and highway needs study purposes.

The default resource requirement estimates (Tables 3.4 and 3.5) did not reflect any specific confidence level or level of allowable error. However, the assumption for sample sizes correspond to an allowable error of +/- 5 mph, and a confidence level of 85%, given a range of speeds of up 10 mph.

Overall, the refined, Central Puget Sound-specific resource requirement estimates are higher than the assumed, or default, estimates. This is consistent with the fact that, as described near the end of Section 4.2, most of the observed off-peak direction speeds were significantly lower than was assumed, and on average, five runs are required rather than four runs.

## TABLE 5.1

## REFINED, CENTRAL PUGET SOUND-SPECIFIC TRAVEL TIME DATA COLLECTION RESOURCE REQUIREMENT ESTIMATES FOR URBAN ROADWAYS: 95% CONFIDENCE LEVEL

| **Facility Type and Duration of Data Collection Period** | **Number of Data Collection Sessions Required (Given Various Amounts of Study Area Mileage and Assuming One GPS Unit)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1 mi.** | **5 mi.** | **10 mi.** | **30 mi.** | **80 mi.** | **150 mi.** | **300 mi.** |
| Data Collection Period = 15 minutes | | | | | | | |
| Freeway - general use lanes | 1.423 | 7.116 | 14.232 | 42.695 | 113.853 | 213.475 | 426.950 |
| Freeway - HOV lanes | 0.876 | 4.379 | 8.758 | 26.274 | 70.064 | 131.370 | 262.740 |
| Arterial - 40 mph | 1.854 | 9.269 | 18.538 | 55.615 | 148.306 | 278.073 | 556.146 |
| Arterial - 35 mph | 1.888 | 9.441 | 18.882 | 56.646 | 151.055 | 283.228 | 566.456 |
| Data Collection Period = 30 minutes | | | | | | | |
| Freeway - general use lanes | 0.712 | 3.558 | 7.116 | 21.348 | 56.927 | 106.738 | 213.475 |
| Freeway - HOV lanes | 0.438 | 2.190 | 4.379 | 13.137 | 35.032 | 65.685 | 131.370 |
| Arterial - 40 mph | 0.927 | 4.635 | 9.269 | 27.807 | 74.153 | 139.037 | 278.073 |
| Arterial - 35 mph | 0.944 | 4.720 | 9.441 | 28.323 | 75.527 | 141.614 | 283.228 |
| Data Collection Period = 60 minutes | | | | | | | |
| Freeway - general use lanes | 0.356 | 1.779 | 3.558 | 10.674 | 28.463 | 53.369 | 106.738 |
| Freeway - HOV lanes | 0.219 | 1.095 | 2.190 | 6.569 | 17.516 | 32.843 | 65.685 |
| Arterial - 40 mph | 0.463 | 2.317 | 4.635 | 13.904 | 37.076 | 69.518 | 139.037 |
| Arterial - 35 mph | 0.472 | 2.360 | 4.720 | 14.161 | 37.764 | 70.807 | 141.614 |
| Data Collection Period =180 minutes | | | | | | | |
| Freeway - general use lanes | 0.119 | 0.593 | 1.186 | 3.558 | 9.488 | 17.790 | 35.579 |
| Freeway - HOV lanes | 0.073 | 0.365 | 0.730 | 2.190 | 5.839 | 10.948 | 21.895 |
| Arterial - 40 mph | 0.154 | 0.772 | 1.545 | 4.635 | 12.359 | 23.173 | 46.346 |
| Arterial - 35 mph | 0.157 | 0.787 | 1.573 | 4.720 | 12.588 | 23.602 | 47.205 |

## TABLE 5.2
## REFINED, CENTRAL PUGET SOUND-SPECIFIC TRAVEL TIME DATA COLLECTION RESOURCE REQUIREMENT ESTIMATES FOR URBAN ROADWAYS: 85% CONFIDENCE LEVEL

| **Facility Type and Duration of Data Collection Period** | **Number of Data Collection Sessions Required (Given Various Amounts of Study Area Mileage and Assuming One GPS Unit)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1 mi.** | **5 mi.** | **10 mi.** | **30 mi.** | **80 mi.** | **150 mi.** | **300 mi.** |
| Data Collection Period = 15 minutes | | | | | | | |
| Freeway - general use lanes | 1.017 | 5.083 | 10.165 | 30.496 | 81.324 | 152.482 | 304.965 |
| Freeway - HOV lanes | 0.701 | 3.503 | 7.006 | 21.019 | 56.051 | 105.096 | 210.192 |
| Arterial - 40 mph | 1.545 | 7.724 | 15.449 | 46.346 | 123.588 | 231.728 | 463.455 |
| Arterial - 35 mph | 1.511 | 7.553 | 15.105 | 45.316 | 120.844 | 226.582 | 453.165 |
| Data Collection Period = 30 minutes | | | | | | | |
| Freeway - general use lanes | 0.508 | 2.541 | 5.083 | 15.248 | 40.662 | 76.241 | 152.482 |
| Freeway - HOV lanes | 0.350 | 1.752 | 3.503 | 10.510 | 28.026 | 52.548 | 105.096 |
| Arterial - 40 mph | 0.772 | 3.862 | 7.724 | 23.173 | 61.794 | 115.864 | 231.728 |
| Arterial - 35 mph | 0.755 | 3.776 | 7.553 | 22.658 | 60.422 | 113.291 | 226.582 |
| Data Collection Period = 60 minutes | | | | | | | |
| Freeway - general use lanes | 0.254 | 1.271 | 2.541 | 7.624 | 20.331 | 38.121 | 76.241 |
| Freeway - HOV lanes | 0.175 | 0.876 | 1.752 | 5.255 | 14.013 | 26.274 | 52.548 |
| Arterial - 40 mph | 0.386 | 1.931 | 3.862 | 11.586 | 30.897 | 57.932 | 115.864 |
| Arterial - 35 mph | 0.378 | 1.888 | 3.776 | 11.329 | 30.211 | 56.646 | 113.291 |
| Data Collection Period =180 minutes | | | | | | | |
| Freeway - general use lanes | 0.085 | 0.424 | 0.847 | 2.541 | 6.777 | 12.707 | 25.414 |
| Freeway - HOV lanes | 0.058 | 0.292 | 0.584 | 1.752 | 4.671 | 8.758 | 17.516 |
| Arterial - 40 mph | 0.129 | 0.644 | 1.287 | 3.862 | 10.299 | 19.311 | 38.621 |
| Arterial - 35 mph | 0.126 | 0.629 | 1.259 | 3.776 | 10.070 | 18.882 | 37.764 |

## TABLE 5.3
## REFINED, CENTRAL PUGET SOUND-SPECIFIC TRAVEL TIME DATA COLLECTION RESOURCE REQUIREMENT ESTIMATES FOR URBAN ROADWAYS: 75% CONFIDENCE LEVEL

| Facility Type and Duration of Data Collection Period | Number of Data Collection Sessions Required (Given Various Amounts of Study Area Mileage and Assuming One GPS Unit) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 mi. | 5 mi. | 10 mi. | 30 mi. | 80 mi. | 150 mi. | 300 mi. |
| Data Collection Period = 15 minutes | | | | | | | |
| Freeway - general use lanes | 0.813 | 4.066 | 8.132 | 24.397 | 65.059 | 121.986 | 243.972 |
| Freeway - HOV lanes | 0.525 | 2.627 | 5.255 | 15.764 | 42.038 | 78.822 | 157.644 |
| Arterial - 40 mph | 1.236 | 6.179 | 12.359 | 37.076 | 98.870 | 185.382 | 370.764 |
| Arterial - 35 mph | 1.133 | 5.665 | 11.329 | 33.987 | 90.633 | 169.937 | 339.873 |
| Data Collection Period = 30 minutes | | | | | | | |
| Freeway - general use lanes | 0.407 | 2.033 | 4.066 | 12.199 | 32.530 | 60.993 | 121.986 |
| Freeway - HOV lanes | 0.263 | 1.314 | 2.627 | 7.882 | 21.019 | 39.411 | 78.822 |
| Arterial - 40 mph | 0.618 | 3.090 | 6.179 | 18.538 | 49.435 | 92.691 | 185.382 |
| Arterial - 35 mph | 0.566 | 2.832 | 5.665 | 16.994 | 45.316 | 84.968 | 169.937 |
| Data Collection Period = 60 minutes | | | | | | | |
| Freeway - general use lanes | 0.203 | 1.017 | 2.033 | 6.099 | 16.265 | 30.496 | 60.993 |
| Freeway - HOV lanes | 0.131 | 0.657 | 1.314 | 3.941 | 10.510 | 19.706 | 39.411 |
| Arterial - 40 mph | 0.309 | 1.545 | 3.090 | 9.269 | 24.718 | 46.346 | 92.691 |
| Arterial - 35 mph | 0.283 | 1.416 | 2.832 | 8.497 | 22.658 | 42.484 | 84.968 |
| Data Collection Period =180 minutes | | | | | | | |
| Freeway - general use lanes | 0.068 | 0.339 | 0.678 | 2.033 | 5.422 | 10.165 | 20.331 |
| Freeway - HOV lanes | 0.044 | 0.219 | 0.438 | 1.314 | 3.503 | 6.569 | 13.137 |
| Arterial - 40 mph | 0.103 | 0.515 | 1.030 | 3.090 | 8.239 | 15.449 | 30.897 |
| Arterial - 35 mph | 0.094 | 0.472 | 0.944 | 2.832 | 7.553 | 14.161 | 28.323 |

## 5.2 Regional Resource Requirement Estimates

The resource requirement estimates using default (assumed) values, presented in Tables 3.6 and 3.7 were updated based on the findings of the field test.

For the first estimate (Table 3.6), the estimate for all interstate and principle arterial roads in the region, only calculations for urban area roads were refined, since no information on rural roads was collected in the field test. The refinements for the urban roads consisted of substituting the observed average sample size for the default assumption, and adjusting the peak and off-peak direction speed relationships based on the observed averages by facility type.

For the second estimate (Table 3.7), the estimate for the much smaller subset of roadways that are the subject of the field test portion of this project, the revised estimate did not utilize the average sample size and speed values obtained from the test results. Rather, the estimates of the additional number of runs required were calculated route by route, based on the specific sample size and speed information observed for each individual route in question. In the relatively few examples where no valid runs were obtained for a particular route, the average sample sizes and speeds for the specific facility types were used.

Both of the refined travel time data collection estimates were made under two scenarios relative to level of confidence: 85% and 75%, values that are appropriate to regionwide planning purposes. The revised regional study area estimates are shown in Tables 5.4 (85% confidence) and 5.5 (75% confidence). The estimate to complete data collection on the roadways that were included in the field test is shown in Table 5.6.

Regional Study Area Estimate

The refined estimate for the region-wide study area (78 weeks, shown in Table 5.4) is about 32% higher than the default estimate (59 weeks, shown in Table 3.6). Both estimates reflect a confidence level of approximately 85% and use of only one GPS unit. Since the Regional Council has purchased two units that can be used for future data collection efforts, the refined estimate should be halved, to 39 weeks. As shown in Table 5.5, at a confidence level of approximately 75%, the estimate drops to approximately 55 weeks (assuming 1 GPS unit), or approximately 28 weeks assuming two units.

The refined estimates are higher than the default estimates because the default estimates assumed significantly higher average speeds in the off-peak direction and assumed only four runs would be required, whereas five runs were found to be required for two of the four facility types (at an 85% confidence level).

## TABLE 5.4
## ESTIMATED NUMBER OF DATA COLLECTION SESSIONS (@ 2 3-HR SESSIONS/DAY) REQUIRED TO COLLECT REGIONAL TRAVEL TIME DATA
## (@ +/- 85% CONFIDENCE LEVEL AND +/- 5 MPH ALLOWABLE ERROR & w/1 GPS Unit)

| **County/Facility Type** | **Centerline Miles** | **Comparable Facility Type From Field Test** | **Number of Data Collection Sessions Needed Per Directional Mile** | **Estimated Number of Data Collection Sessions Needed (In Days)** | **Estimated Number of Data Collection Sessions Needed (In Weeks) *** |
|---|---|---|---|---|---|
| King | | | | | |
| Rural Interstate | 33.0 | None - use default | 0.036 | 2 | |
| Rural PA Other | 41.7 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 80.6 | Freeway - general use lanes | 0.085 | 14 | |
| Urban Principal Arterial - Freeway/Expressway | 105.7 | Freeway - general use lanes | 0.085 | 18 | |
| Urban Principal Arterial - Other | 345.7 | Arterial - 40 mph | 0.129 | 89 | |
| Subtotal | 606.7 | | | 128 | 43 |
| Kitsap | | | | | |
| Rural Interstate | 0.0 | None - use default | 0.036 | 0 | |
| Rural PA Other | 39.8 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 0.0 | Freeway - general use lanes | 0.085 | 0 | |
| Urban Principal Arterial - Freeway/Expressway | 22.5 | Freeway - general use lanes | 0.085 | 4 | |
| Urban Principal Arterial - Other | 39.2 | Arterial - 40 mph | 0.129 | 10 | |
| Subtotal | 101.5 | | | 18 | 6 |
| Pierce | | | | | |
| Rural Interstate | 3.4 | None - use default | 0.036 | 0 | |
| Rural PA Other | 4.2 | Arterial - 40 mph | 0.054 | 0 | |
| Urban Interstate | 22.7 | Freeway - general use lanes | 0.085 | 4 | |
| Urban Principal Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.085 | 5 | |
| Urban Principal Arterial - Other | 175.7 | Arterial - 40 mph | 0.129 | 45 | |
| Subtotal | 237.8 | | | 55 | 18 |
| Snohomish | | | | | |
| Rural Interstate | 13.9 | None - use default | 0.036 | 1 | |
| Rural PA Other | 44.8 | Arterial - 40 mph | 0.054 | 5 | |
| Urban Interstate | 31.3 | Freeway - general use lanes | 0.085 | 5 | |
| Urban Principal Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.085 | 5 | |
| Urban Principal Arterial - Other | 64.0 | Arterial - 40 mph | 0.129 | 17 | |
| Subtotal | 185.9 | | | 33 | 11 |
| Regional Totals | | | | | |
| Rural Interstate | 50.33 | None - use default | 0.036 | 4 | |
| Rural PA Other | 130.41 | Arterial - 40 mph | 0.054 | 14 | |
| Urban Interstate | 134.53 | Freeway - general use lanes | 0.085 | 23 | |
| Urban Principal Arterial - Freeway/Expressway | 192 | Freeway - general use lanes | 0.085 | 33 | |
| Urban Principal Arterial - Other | 624.6 | Arterial - 40 mph | 0.129 | 161 | |
| **Total** | **1,131.9** | | | **234** | **78** |

*** Assumes data collection only on Tue, Wed and Thur**

## TABLE 5.5
## ESTIMATED NUMBER OF DATA COLLECTION SESSIONS (@ 2 3- HR SESSIONS/DAY) REQUIRED TO COLLECT REGIONAL TRAVEL TIME DATA (@ +/- 75% CONFIDENCE LEVEL AND +/- 5 MPH ALLOWABLE ERROR & w/1 GPS UNIT)

| County/Facility Type | Centerline Miles | Comparable Facility Type From Field Test | Number of Data Collection Sessions Needed Per Directional Mile | Estimated Number of Data Collection Sessions Needed (In Days) | Estimated Number of Data Collection Sessions Needed (In Weeks) * |
|---|---|---|---|---|---|
| King | | | | | |
| Rural Interstate | 33.0 | Freeway - general use lanes | 0.036 | 2 | |
| Rural PA Other | 41.7 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 80.6 | Freeway - general use lanes | 0.068 | 11 | |
| Urban Principal Arterial - Freeway/Expressway | 105.7 | Freeway - general use lanes | 0.068 | 14 | |
| Urban Principal Arterial - Other | 345.7 | Arterial - 40 mph | 0.103 | 71 | |
| Subtotal | 606.7 | | | 103 | 34 |
| Kitsap | | | | | |
| Rural Interstate | 0.0 | Freeway - general use lanes | 0.036 | 0 | |
| Rural PA Other | 39.8 | Arterial - 40 mph | 0.054 | 4 | |
| Urban Interstate | 0.0 | Freeway - general use lanes | 0.068 | 0 | |
| Urban Principal Arterial - Freeway/Expressway | 22.5 | Freeway - general use lanes | 0.068 | 3 | |
| Urban Principal Arterial - Other | 39.2 | Arterial - 40 mph | 0.103 | 8 | |
| Subtotal | 101.5 | | | 15 | 5 |
| Pierce | | | | | |
| Rural Interstate | 3.4 | Freeway - general use lanes | 0.036 | 0 | |
| Rural PA Other | 4.2 | Arterial - 40 mph | 0.054 | 0 | |
| Urban Interstate | 22.7 | Freeway - general use lanes | 0.068 | 3 | |
| Urban Principal Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.068 | 4 | |
| Urban Principal Arterial - Other | 175.7 | Arterial - 40 mph | 0.103 | 36 | |
| Subtotal | 237.8 | | | 44 | 15 |
| Snohomish | | | | | |
| Rural Interstate | 13.9 | Freeway - general use lanes | 0.036 | 1 | |
| Rural PA Other | 44.8 | Arterial - 40 mph | 0.054 | 5 | |
| Urban Interstate | 31.3 | Freeway - general use lanes | 0.068 | 4 | |
| Urban Principal Arterial - Freeway/Expressway | 31.9 | Freeway - general use lanes | 0.068 | 4 | |
| Urban Principal Arterial - Other | 64.0 | Arterial - 40 mph | 0.103 | 13 | |
| Subtotal | 185.9 | | | 28 | 9 |
| Regional Totals | | | | | |
| Rural Interstate | 50.33 | Freeway - general use lanes | 0.036 | 4 | |
| Rural PA Other | 130.41 | Arterial - 40 mph | 0.054 | 14 | |
| Urban Interstate | 134.53 | Freeway - general use lanes | 0.068 | 18 | |
| Urban Principal Arterial - Freeway/Expressway | 192 | Freeway - general use lanes | 0.068 | 26 | |
| Urban Principal Arterial - Other | 624.6 | Arterial - 40 mph | 0.103 | 129 | |
| **Total** | **1,131.9** | | | **191** | **64** |

*** Assumes data collection only on Tue, Wed and Thur**

## TABLE 5.6
## REFINED ESTIMATE OF ADDITIONAL NUMBER OF DATA COLLECTION SESSIONS (@ 2 HRS EA.) REQUIRED FOR STUDY CORRIDORS: USING OBSERVED VALUES
## (@ +/- 85% AND +/- 75% CONFIDENCE LEVELS AND +/- 5 MPH ALLOWABLE ERROR & w/1 GPS UNIT)

| | | Estimated Number of Additional Data Collection Sessions Required by Confidence Level | | | |
|---|---|---|---|---|---|
| | | # of Days | | # of Weeks | |
| **Corridor** | **Centerline Miles of Study Roadway** | **85%** | **75%** | **85%** | **75%** |
| 148th Ave SE/NE | 6.7 | 1 | 0 | 0 | 0 |
| I-5/Stewart SB-Olive NB/4th Ave | 50.4 | 10 | 7 | 3 | 2 |
| I-90 | 20.4 | 3 | 2 | 1 | 1 |
| I-405 | 40.8 | 6 | 5 | 2 | 2 |
| SR 16/I-5 | 11.1 | 5 | 4 | 2 | 1 |
| SR 520 | 12.1 | 2 | 1 | 1 | 0 |
| SR 99 | 33.2 | 9 | 6 | 3 | 2 |
| SR 522 | 12.5 | 3 | 2 | 1 | 1 |
| SR 16/SR 3/SR 304 | 9.3 | 1 | 1 | 0 | 0 |
| SR 524 | 5.9 | 1 | 1 | 0 | 0 |
| S 180th St/SW 43rd St/Carr Rd SE | 2.4 | 1 | 0 | 0 | 0 |
| **Total** | **204.8** | **42** | **30** | **14** | **10** |

*** Assumes data collection only on Tue, Wed and Thur**

Field Test Study Area Estimate

*Estimated Resources Required to Complete the Field Test Data Collection*

The estimate to complete the data collection effort on the field test study corridors (Table 5.6) indicates that, assuming an 85% level of confidence, approximately 14 additional weeks of data collection are required. For consistency, the estimate in Table 5.6 also assumes that one GPS unit is used. ***If both of the available units are used, only approximately 7 weeks of additional data collection are required, roughly equivalent to the effort that was put in during the field test.*** Note that this estimate was not derived using the resource requirements estimation formula and the field test observed values for speeds and sample size, which would consist of multiplying the average per mile data collection session estimates (Tables 5.1 – 5.3) by the total miles by facility type. Rather, this estimate was derived by adding up the "additional sessions" for each individual segment, peak period and direction, as portrayed in 4.2.

*Accuracy of the Requirements Estimation Formula – Predicted Vs. Observed*

Table 5.7 summarizes the default and revised estimates, given a standardized number of assumed GPS units available (3), which aids in comparison. The estimated total effort needed to collect data for the field test corridors (actual effort to date plus estimated remaining effort) is significantly higher than the default estimate, approximately twice as high. As previously noted, part of the difference is explained by the fact that the default estimate underestimated the number of runs required for some facility types and overestimated the off-peak direction travel speeds. If the refined values for these factors are utilized—the values derived from the field test, the estimate increases from 5.3 weeks (as shown in Table 5.7) to 6.3 weeks. Clearly, even with the refined values, the resource requirements formula significantly underestimates the data collection effort. This suggests that the formula fails to account for time that is somehow lost during the data collection effort.

**TABLE 5.7**
**SUMMARY COMPARISON OF DEFAULT AND REVISED ESTIMATES**
**FOR FIELD TEST STUDY AREA DATA COLLECTION**

| Number of GPS Units | Weeks of Data Collection (Assuming 4 hours/day & 3 days/wk) | | | |
|---|---|---|---|---|
| | Estimate Using Default Values (@ +/- 85% Confidence) | Actual Plus Revised Estimate | | |
| | | Actual Work Done in Field Test | Estimated Additional Work Remaining (@ +/- 85% Confidence) | Total |
| 3 | 5.3 | 7.0 | 4.7 | 11.7 |

There are three factors that can result in lost or wasted time and thus increase the amount of effort needed to collect a given amount of data. The first factor is time within a given data collection session that is left unused ("remnants") because the remaining time within a given session is inadequate for another full run. The second factor, "repositioning time" is the time lost within a given data collection session spent getting from one corridor end point to the next corridor start point. The third factor, “invalid runs”, is the time lost spent collecting data that is later identified as invalid and must be recollected. The failure to account for these factors in the estimation formulas explains why the actual data collection effort took much longer than would be predicted.

Based on the information in Table 5.7, it appears that the regional study resource estimates in Tables 5.5 and 5.6 should be viewed as minimum estimates, with the actual data collection resources potentially being as great as twice as much. It is currently not advisable to attempt to adjust the estimation formula to account for the lost time factors. This is because the influence of the factors will vary depending on the specific data collection plan, and, in at least one case (invalid runs), will significantly decrease in future data collection efforts.

First, the amount of “remnant” time that is lost varies based on the length of the corridors—longer corridors result in potentially longer remnants. For example, given a two-hour study period, if one long corridor takes 80 minutes, depending on how the driver is instructed relative to the timing of runs in relation to the beginning and end of the study period, as much as 40 minutes, or 1/3 of the available time, could be lost. If shorter runs are made, the amount of time lost will be reduced. Second, the amount of “repositioning” lost time will vary depending on the number of corridors that are run within a given data collection session and their proximity. Finally, the number of invalid runs can be expected to reduce significantly when the dead reckoning equipped units are used, when the influence of satellite repositioning is avoided and as greater familiarity with the data collection units and procedures is acquired.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

Although the project resources did not allow full investigation of all of the issues associated with travel time data collection, and there are many, the project effort was successful in accomplishing it's primary objectives. A GPS data collection methodology was developed and field-tested and demonstrated the effectiveness of the GPS technique. A resource estimation technique was developed and tested, and although found to significantly underestimate the resources required for the field test, the reasons for that under estimation have been identified conceptually and can be quantified based on the results of further experience. Finally, a large amount of valid travel time data was collected.

## 6.1 Advantages Relative to Alternative Techniques

- ***Although still fairly resource-intensive, the GPS technique is far superior to the manual test vehicle approach.*** Although the labor resources required with the GPS technique are still relatively high for large data collection efforts, they are at least half of what could be expected using traditional manual test car techniques, and constitute one of the major benefits of the technique. For major region wide data collection it is recommended that a different approach be utilized. The recommended approach should eliminate the need for paid vehicle operators and should feature wireless transmission of GPS data from the vehicle to a remote storage location, eliminating the need to store the data on board the vehicle. There are several emerging wireless technologies that enable such an approach, in some cases using GPS, as further discussed below.

- ***GPS coupled with GIS is a powerful combination and a major justification for using the GPS approach.*** Although resource limitations prevented full investigation of the use of GIS to analyze and display GPS travel time data, the benefits are apparent, and along with the reduced labor requirement, constitutes a powerful justification for use of the GPS technique. It can be reasonably assumed that as familiarity increases the effort required to clean, reduce, analyze and display travel time information using GIS will be considerably less than is required with manually recorded data. Also, the extremely rich and detailed data that can be obtained using the GPS approach , consisting of data points every few seconds, coupled with the powerful analysis and display capabilities of GIS provides for a level of detail impossible with manually recorded data. The Regional Council played a major role in the data reduction and analysis phase of this study, and to some extent, has already developed familiarity with and demonstrated the utility of GIS in manipulating GPS travel time data.

- ***The GPS approach that was tested is generally cost-effective only for smaller study areas; for large scale, system wide performance monitoring, the applicability of alternative techniques utilizing emerging technologies should be evaluated.*** Driver labor costs make large scale data collection using the GPS technique expensive, more or less so depending on the pay rates. As shown in Table 6.1, the data collection approaches that avoid driver compensation include significant infrastructure costs, either direct (in the case of publicly owned systems) or indirect (where privately owned infrastructure is utilized on a fee basis). There are two options in particular that should be monitored for future application (summarized in Table 6.2). The first option utilizes privately owned cellular telephone infrastructure, either on a fee basis, or for "free" in exchange for public support of the communications infrastructure and operations costs. This option is expensive (e.g., typically millions of dollars for complete coverage of a large region), but can provide data of interest to a number of different agencies. In order to keep costs manageable, this option would require that multiple agencies pool their data needs and resources. The second option consists of providing a relatively large number of (e.g., more than 20) small, inexpensive GPS receiver-equipped electronic devices, such as palm top computers, to a group of drivers. The devices would require no special operating instructions (other than being turned on) and would automatically transmit GPS data back to a central location using a wireless modem technology, such as cellular telephone. Both of these approaches gather data through normal, day-to-day driving, as opposed to explicit, pre-planned travel time runs made using the "floating car" technique. Therefore, it is especially important that enough samples be collected to provide statistically valid results.

## 6.2 GPS Equipment and Data Collection Protocol

- ***The basic GPS technique is fairly well established and reliable, and although it eliminates several sources of error, it does not eliminate all sources of error nor the need for operator training and diligence***.

- ***The Regional Council should continue to use and perfect the GPS approach.*** A few technological difficulties were encountered, including difficulties with batteries, resetting of data loggers, GPS coverage gaps and errors and gaps associated with changes in the government satellite system. However, these difficulties will increasingly be avoided in over time. Experience with the technology and equipment will reduce human errors and result in refinements to procedures.

- ***When scheduling major data collection efforts, the status of the US Coast Guard's GPS differential correction service, and the status of the GPS satellites, should be verified.*** Information on the US Coast Guard differential correction service can be obtained at the web site, "www.navcen.uscg.mil". Information on the GPS satellite system can be obtained at the Shriever Air Force Base web site, "http://www.schriever.af.mil/gps/".

## TABLE 6.1
## COST IMPLICATIONS OF TRAVEL TIME DATA COLLECTION TECHNIQUES (Adapted from reference 4)

| | | CostsTypically Paid by the Organization Desiring the Data | | |
|---|---|---|---|---|
| **Travel Time Data Collection Technique** | **Summary Description** | **In-vehicle equipment costs** | **Driver labor costs** | **Infrastructure costs** |
| **Probe Vehicles Techniques:** | | | | |
| Manual Test Vehicle | Same technique as evaluated in this study but without GPS; times at check points are recorded. | | **X** | |
| GPS Test Vehicle | The technique evaluated in this study. | **X** | **X** | |
| Cell Phone Geolocation | A number of different emerging technologies may be employed, including triangulation or position matching. Only requires that the cell phone is being utilized. | | | **X** |
| Automated Vehicle Identification | Probe vehicles are equipped with electronic tags that communicate with roadside tranceivers. Typically used in areas where there is a large existing base of toll tags already installed. | **Usually Not** | | **X** |
| Ground-Based Radio Navigation | Often used for transit or commercial fleets. Locations are determined by radio trilateration. Requires conventional mobile radio infrastructure and in-vehicle radios. | **X** | | **X** |
| Signpost automatic vehicle location (AVL) | Typically used by transit agencies. Probe vehicles communicate with roadside transmitters to establish vehicle location. | **X** | | **X** |
| **Infrastructure Techniques:** | | | | |
| Extrapolation from Spot Locations | Estimates travel times for short segments based on spot locations (e.g., using inductive loop vehicle detectors). | | | **X** |
| Vehicle Signature Mapping | Matches unique electronic vehicle signatures between separate observation points, utilizing a number of spot location detectors (e.g., inductive loops). | | | **X** |
| Platoon Matching | Matches unique features of vehicle platoon, like the position and/or distribution of vehicle gaps or unique vehicles. Uses spot detection devices like video cameras. | | | **X** |
| Aerial Surveys | Uses aerial camera surveys that measure traffic density. | | | **X** |

Note: an additional technique, license plate matching, has not been included because it is not effective for large study areas where detailed data is required.

## TABLE 6.2
## TWO EMERGING OPTIONS FOR LARGE SCALE TRAVEL TIME DATA COLLECTION

| **Data Collection Option** | **Summary Description** | **Primary Advantages Relative to the GPS Test Vehicle Technique** | **Primary Disadvantages Relative to the GPS Test Vehicle Technique** |
|---|---|---|---|
| "Network" Private Cell Phone Geolocation | The location, speed, direction and acceleration of vehicles is determined using special cell phone communications infrastructure, such as US Wireless' RadioCamera$^{TM}$ pattern-matching technology. The public agency either pays for specific data or pays for the required infrastructure and/or operations expenses and receives all data for "free". | 1. Drivers do not need to be paid to make specific "runs". Data collection happens "automatically" using existing cell phones whenever they are in use.<br>2. A very large number of devices is deployed and data can be collected very quickly, allowing for tracking changes week-to-week, month-to-month, etc. | 1. Although vendor's refer to the data probes as "anonymous", there may be perceived privacy issues.<br>2. The infrastructure necessary to provide complete coverage throughout a large region could cost several million dollars. |
| Inexpensive GPS Device w/Wireless Data Transmission | A relatively large number of small, inexpensive hand-held electronic devices, such as palm-top computers, are provided to volunteer drivers. The devices automatically transmit GPS location information to a central location using a wireless modem technology, such as cellular telephone. Would not include real-time differential correction. | 1. Drivers do not need to be paid to make specific "runs". Data collection happens "automatically" whenever the device is turned on.<br>2. Since more devices are deployed than would be the case with the GPS test vehicle technique, data can be collected more quickly, although less quickly than with the cell phone technique. | 1. Although relatively inexpensive (e.g., +/- $10 per month per device), there are costs for the wireless data transmission.<br>2. Although less expensive on a per-device basis than the full GPS receiver set-up evaluated in this study, the overall cost for the GPS devices would be higher since many of them would be deployed.<br>3. Since no real-time differential correction would be performed, either post-processed differential correction would be required, or other techniques would be needed to address the "GPS data gap" issue for areas such as tunnels. |

- ***Although GPS equipment sets have essentially become "off-the-shelf", a significant amount of effort can be required to install and fine-tune a particular equipment set.*** The Regional Council's experience with the Trimble Placer 455DR GPS units, the units purchased by the Regional Council but that were not available during the field test, supports this assertion. The de-bugging and fine tuning process has not been completed. To date, several difficulties have been encountered:

  - The claimed level of positional accuracy has not been achieved.

  - The dead-reckoning unit installation has proven challenging, requiring the installation of equipment that cannot be easily moved from vehicle to vehicle.

  - It has been difficult to consistently collect good data, possibly due to problems with the mounting of the accelerometer.

  - It has been observed that the dead reckoning unit must be properly calibrated at all times, since the dead reckoning signal is used continuously, not just when satellite communication is obstructed.

- ***The GPS units that were leased for use in the field test (Trimble Pathfinder Pros) are capable of and were found to achieve higher levels of positional accuracy than the units that were recommended based on the equipment review (Trimble Placer 455DRs, which have been purchased by the Regional Council).*** The leased units do not include dead-reckoning devices, which, although it eliminates the possibility of collecting data in areas where the GPS satellite signal is obscured by tall buildings, dense foliage, etc., it eliminates the complications and portability restrictions associated with the dead-reckoning devices. Given these considerations, in cases where data gaps are less of a concern than the accuracy and portability of the units—and therefore their adaptability to a range of other applications, including infrastructure inventories—the Pathfinder Pro units may be preferable.

- ***The GPS technique reduces but does not eliminate the influence of human error, and adequate training and test runs are necessary.*** Until such time as the equipment is 100% automated, the value of the data will be significantly influenced by the skill and care taken in operating the GPS units. Even when operation of the technology is eliminated as a variable, as long as people are driving the test vehicle, judgement must be exercised and procedures must be followed consistently from session to session and from driver to driver. Prior to performing the actual data collection runs, data collectors should perform test runs and identify specific turn-around points. Also, it is very important that different drivers operate the test vehicles consistently, and that drivers operate the vehicles consistently from one run to another. For example, staying in the middle lane and attempting to pass only as many cars as pass them (the traditional "floating car" technique). It is also recommended that weather and traffic reports be consulted prior to data collection runs, in order to avoid atypical conditions and to fine-tune run scheduling.

- ***Drivers should record the cause of major delays or other incidents, and utilize standard coding and naming conventions.*** The frequency of sampling associated with the GPS technique, coupled with the GIS capability to precisely relate sampling points to actual locations within the transportation infrastructure, significantly reduces the need to record supplemental field information pertaining to the location of delays and other unusual conditions that affect travel time. However, the cause of the delays is sometimes difficult to determine without notes from the data collector, a requirement that is reduced, but not eliminated, by using the GPS technique. This information, along with start and end times should be recorded, either manually in a standardized log book, or using the GPS data logger or laptop computer (depending on the specific GPS unit), which have function keys that can be used to record conditions such as various types of incidents.

## 6.3 Sample Sizes and Resource Requirements

- ***A formula was developed to estimate resource requirements that includes the following variables: sample size (number of runs required); route mileage; the number of GPS units to be used; and the number of miles that can be covered per data collection session per GPS unit/test vehicle.*** The formula does not include the following additional factors that can significantly increase the amount of time and effort required to collect a given amount of data: time lost between the end of one run and the start of the next run ("repositioning time"); runs that must be repeated due to invalid data (e.g., equipment failures or operator errors); and the unusable, "left over" periods of time in each data collection that are insufficient to make another run. These variables and their significance in future data collection efforts are summarized in Table 6.3. As noted in Table 6.3, the influence of these additional factors depends heavily on the structure of the data collection effort, and can be partially controlled. For example, as data collectors become more familiar with the GPS units and data collection protocols, the number of repeated runs due to invalid data will decrease.

- ***The field test results indicate that the resource requirements estimation formula underestimated the actual resources required by approximately one-half, due to the influence of the three factors that are not accounted for in the formula (seeTable 6.3).*** Therefore, estimates made using the formula should be doubled.

## TABLE 6.3
## VARIABLES NOT REFLECTED IN THE RESOURCE REQUIREMENTS ESTIMATION FORMULA AND THEIR FUTURE SIGNIFICANCE

| Variables Not Reflected in Resource Requirements Estimation Formula | Description | Significance in Future Travel Time Studies |
|---|---|---|
| Repositioning Time | Lost time during a data collection period spent getting from one segment end point to the next start point | Not a factor unless more than one study corridor will be run within a single data collection period. Even then, the lost time can be minimized by laying out the start and end points efficiently. |
| Invalid Runs | Data that must be recollected due to errors or omissions discovered after the run is completed | Will become less and less of a factor as human errors are reduced through experience, as the data collection protocol is perfected, when the dead reckoning-equipped units are used, and when disruptions due to satellite changes are avoided. Although the percentage of invalid data will drop significantly, there will always be some loss. |
| Wasted Time "Remnants" | Unused portions of a data collection session that are too brief to complete an additional full run | Will vary depending on the length of the runs—longer runs create the potential for larger unused "remnants". Also will vary depending on the data collection protocol regarding run start and end times in relation to the end of the study session. |

- ***Travel time data collection using any sort of test vehicle approach is fairly labor-intensive and the resources required to collect data over large areas are considerable.*** This suggests that, like traffic count programs, travel time data collection efforts over large areas should be viewed as on-going rather than periodic, short-term activities. In terms of the application of GPS travel time data collection techniques to CMS monitoring, the results of this study indicate that collecting data for the entire Metropolitan Transportation System being monitored for the CMS would not be cost feasible. Therefore, it is recommended that data be collected on a limited number of corridors only, and that an initial screening process be developed that will allow the Regional Council to focus available resources on the most critical locations, e.g., the most congested, most traveled corridors.

- ***Consider the trade-offs between cost and data applicability carefully.*** Resource requirements are a function of a number of interrelated variables, and will vary considerably depending on the application, desired level of accuracy and validity. Ultimately, given limited resources, trade-offs must be accepted. Table 6.4 summarizes the influence of some of these variables.

### TABLE 6.4
### KEY VARIABLES AND THEIR INFLUENCES ON RESOURCE REQUIREMENTS AND APPLICABILITY OF RESULTS

| **Variable** | **Primary Influences on Resource Requirements and/or Applicability of Results (Other Factors Being Equal)** |
|---|---|
| Duration of the analysis period (e.g., 3-hour AM peak, etc.) | • Longer periods result in increased travel time/speed variation between runs made at different times, resulting in larger required sample sizes and increased resources<br>• Longer periods increase the amount of data that can be collected per session, reducing the number of days of data collection and reduced resources |
| Length of corridor segments | • Longer segments will tend to demonstrate greater variability in travel times/speeds for various sub-segments along their length, since it is difficult to complete long segments within homogenous, true "peak", travel conditions. This can limit how the results can be applied (e.g., not comparing equivalent conditions). |
| Allowable error | • The higher the allowable error, the smaller the sample size and resource requirements.<br>• Higher error levels are inappropriate to detailed operational analyses. |
| Confidence level | • The higher the desired confidence level, the greater the ability to generalize the results (the better the approximation of a truly typical condition).<br>• The higher the desired level of confidence, the larger the required sample size and resource requirements |

- ***Plan the study design in accordance with the specific intended uses of the data.*** The specific objectives of the travel time study will dictate the study design, and therefore the resources required to complete the data collection effort. Specific details of the travel time data collection methodology have significant implications for how the results can reasonably be applied (see Table 6.3). Segmentation of the analysis corridors is a key consideration that will impact the data collection methods and how the data can be used. Research (Quiroga and Bullock, 1998) and consultant team experience on other projects suggest that breaking corridors up into segments that can be driven in approximately 15 minutes is an effective approach which should be given consideration in future data collection efforts.

- ***Until further testing and refinement can be performed, the estimates produced with the resource requirement estimation formula should be doubled.*** The formula does not accurately account for three factors that can significantly increase the amount of time needed to collect a given amount of data, as explained in Table 6.4. The influence of the three factors depends heavily on the structure of the data collection effort, and can be partially controlled. The role of one of the factors—repeat runs due to invalid data, can be expected to decrease significantly in the future.

# REFERENCES

1. Manual of Traffic Engineering Studies. Institute of Transportation Engineers. Washington D.C. 1994.

2. Quiroga, C.A.. and Bullock, D., 1998. “Determination of Sample Sizes for Travel Time Studies.” ITE Journal, August, pp. 92-98.

3. Quiroga, C.A., and Bullock D., 1996. “Architecture of a Congestion Management System Controlled Access Facilities.” Transportation Research Record 1551, Transportation Research Board, National Research Council, Washington, DC, pp. 105-113.

4. Quiroga, C.A., and Bullock, D., 1999. “Travel Time Information Using GPS and Dynamic Segmentation Techniques.” Transportation Research Record 1660, Transportation Research Board, National Research Council, Washington, DC pp.48-57.

# APPENDIX

## A - GPS Receiver Evaluation Results

## B – Detailed Travel Time Run Data

# Appendix A – GPS Receiver Evaluation

A variety of GPS receiver configurations are available in the market. A summary of technical characteristics and expected costs is given below.

## Trimble Placer 450/455DR

This is a unit that requires system integration before it can be used in the field. Because the unit does not have any data storage capabilities, it is necessary to provide a laptop or handheld device and integrate the system into a unit that can be easily carried, deployed, and stored. In addition, some software customization may be required to filter out data from the output data string so that only time stamps, coordinates, and speed data are kept (apparently, there is an option to output data using a comma-delimited text format; if so, the need for software customization could be eliminated). Differential correction data can be provided to the GPS receiver through (a) FM subcarriers, (b) US Coast Guard Beacon receivers, or (c) L1-band satellite receivers. The Placer 455 unit can support dead-reckoning capabilities through the use of an external heading sensor attachment and wiring to the vehicle odometer and back up lights (taxi meter shops could easily do this wiring).

## CSI ABX-3 Differential Beacon Receiver

This unit is not a GPS receiver. This unit is a receiver of differential correction data from the US Coast Guard Beacon network and can be attached to any GPS receiver that supports the RTCM format.

## CSI GBX

This unit is a combined GPS receiver and a beacon receiver. It does not have data storage capabilities and, consequently, a device like a laptop computer or a handheld device is required. Note: find out whether the GPS control software can be used to drive the GPS data collection process as opposed to just defining data collection parameters.

## Ashtech ProMARK X

This is a standalone unit that can be used for a variety of purposes, including traffic monitoring and inventory (it allows users to store attribute information associated with individual position fixes). Its two main advantages are that it does not require separate data storage devices and that it can export data in a variety of ready-to-use formats. Its main disadvantage is the lack of dead-reckoning capabilities.

### Magellan 750NAV

This unit is a standalone unit designed to provide navigational information to drivers. It uses a Navtech geographic database that is used to display a vicinity map on the unit screen, assist in the routing and guidance process, and match the GPS data to the vector representation of the highway network. The outputted GPS data is "map-matched" data, i.e. it overlays the linear elements representing the directional centerlines of the roadway network.

Following a review of each system's capabilities, ease of installation and use, and its dead reckoning utilization it was decided that the optimal system was the Trimble 455DR.

# Appendix B – Detailed Travel Time Run Data

## DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148 Ave. SE | I-90 to Redmond Rd | Arterial | 3.31 | AM | NB | 10/26/99 | 9.98 | 19.9 | 7.9 | 27.3 | 15 | tbl148seG_148nam1 |
| | | | | AM | NB | 11/11/99 | 5.75 | 34.6 | | | | tbl148seG_148nam2 |
| | | | | PM | NB | 10/26/99 | 6.6 | 30.1 | 7.7 | 26.3 | 8 | tbl148seG_148npm1 |
| | | | | PM | NB | 11/4/99 | 8.82 | 22.5 | | | | tbl148seG_148npm2 |
| | | | | AM | SB | 10/26/99 | 8.57 | 23.2 | 7.0 | 29.7 | 13 | tbl148seG_148sam1 |
| | | | | AM | SB | 11/11/99 | 5.48 | 36.3 | | | | tbl148seG_148sam3 |
| | | | | PM | SB | 10/26/99 | 8.73 | 22.8 | 9.1 | 22.0 | 2 | tbl148seG_148spmak |
| | | | | PM | SB | 11/4/99 | 9.4 | 21.2 | | | | tbl148seG_148s1pm |
| | Redmond Rd to Redmond Way | Arterial | 3.36 | AM | NB | 10/26/99 | 10.47 | 19.2 | 10.0 | 20.3 | 2 | tbl148seG_148nam1 |
| | | | | AM | NB | 11/11/99 | 9.47 | 21.3 | | | | tbl148seG_148nam2 |
| | | | | AM | SB | 11/11/99 | 10.37 | 19.4 | | | | tbl148seG_148sam4 |
| | | | | PM | NB | 10/26/99 | 9.7 | 20.8 | 10.8 | 18.8 | 4 | tbl148seG_148npm1 |
| | | | | PM | NB | 11/4/99 | 11.95 | 16.9 | | | | tbl148seG_148npm2 |
| | | | | PM | SB | 10/26/99 | 10.33 | 19.5 | | | | tbl148seG_148spm |
| I-405 | SE 8th Street to SR 520 | Freeway - general lanes | 2.05 | AM | NB | 11/3/99 | 11.75 | 10.5 | 7.1 | 31.4 | 42 | tbli405G_i405n2am |
| | | | | AM | NB | 10/28/99 | 2.35 | 52.4 | | | | tbli405G_i405nam |
| | | | | AM | SB | 10/28/99 | 2.30 | 53.5 | | | | tbli405G_i405s1am |
| | | | | PM | NB | 10/28/99 | 2.70 | 45.6 | 2.3 | 54.3 | 18 | tbli405G_i405npm |
| | | | | PM | NB | 11/2/99 | 1.95 | 63.1 | | | | tbli405G_sr405nbp |
| | | | | PM | SB | 10/28/99 | 10.92 | 11.3 | 7.5 | 20.6 | 19 | tbli405G_i405spm1 |
| | | | | PM | SB | 11/2/99 | 4.10 | 30.0 | | | | tbli405G_sr405sbp |
| | SR 520 to NE 85th St | Freeway - general lanes | 3.26 | AM | NB | 10/28/99 | 3.35 | 58.4 | 3.2 | 60.4 | 4 | tbli405G_i405nam |
| | | | | AM | NB | 11/3/99 | 3.13 | 62.5 | | | | tbli405G_i405niam |
| | | | | AM | SB | 11/3/99 | 4.4 | 44.5 | 4.4 | 44.3 | 0 | tbli405G_i405sam |
| | | | | AM | SB | 10/20/99 | 4.43 | 44.2 | | | | tbli405G_sr5204051 |
| | | | | PM | NB | 11/3/99 | 13.47 | 14.5 | 7.7 | 35.7 | 48 | tbli405G_i405n1pm |
| | | | | PM | NB | 10/28/99 | 3.13 | 62.5 | | | | tbli405G_i405npm |
| | | | | PM | NB | 11/2/99 | 6.5 | 30.1 | | | | tbli405G_sr405nbp |
| | | | | PM | SB | 10/28/99 | 3.15 | 62.1 | 3.9 | 53.5 | 26 | tbli405G_i405spm1 |
| | | | | PM | SB | 11/3/99 | 5.37 | 36.4 | | | | tbli405G_i405spm2 |
| | | | | PM | SB | 11/2/99 | 3.15 | 62.1 | | | | tbli405G_sr405sbp |
| | NE 85th St to SR 522 | Freeway - general lanes | 5.61 | AM | NB | 10/28/99 | 6 | 56.1 | 5.7 | 59.4 | 7 | tbli405G_i405nam |
| | | | | AM | NB | 11/3/99 | 5.37 | 62.7 | | | | tbli405G_i405niam |

**DETAILED TRAVEL TIME RUN DATA**

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | AM | SB | 10/28/99 | 18.33 | 18.4 | 30.3 | 13.2 | 10 | tbli405G_i405s2am |
| | | | | AM | SB | 11/3/99 | 42.32 | 8.0 | | | | tbli405G_i405sam |
| | | | | PM | NB | 10/28/99 | 6.85 | 49.2 | 8.7 | 41.7 | 22 | tbli405G_i405npm |
| | | | | PM | NB | 11/2/99 | 6.85 | 49.2 | | | | tbli405G_sr405nbp |
| | | | | PM | NB | 11/3/99 | 12.53 | 26.9 | | | | tbli405G_i405n1pm |
| | | | | PM | SB | 10/28/99 | 5.55 | 60.7 | 5.7 | 59.6 | 2 | tbli405G_i405spm1 |
| | | | | PM | SB | 11/3/99 | 5.73 | 58.8 | | | | tbli405G_i405spm2 |
| | | | | PM | SB | 11/2/99 | 5.68 | 59.3 | | | | tbli405G_sr405sbp |
| | SR 522 to SR 524 | Freeway - general lanes | 3.05 | AM | SB | 10/28/99 | 35.32 | 5.2 | 23.6 | 10.3 | 10 | tbli405G_i405s2am |
| | | | | AM | SB | 11/3/99 | 11.88 | 15.4 | | | | tbli405G_i405sam |
| | | | | PM | NB | 10/28/99 | 12.58 | 14.6 | | | | tbli405G_i405npm |
| | | | | PM | SB | 10/28/99 | 4.77 | 38.4 | 3.8 | 50.7 | 27 | tbli405G_i405spm1 |
| | | | | PM | SB | 11/3/99 | 3.75 | 48.8 | | | | tbli405G_i405spm2 |
| | | | | PM | SB | 11/2/99 | 2.82 | 64.9 | | | | tbli405G_sr405sbp |
| I-5 | Pacific Ave to 128th St SE | Freeway - general lanes | 7.37 | AM | NB | 11/9/99 | 18.17 | 24.3 | | | | tbli005G_i5nevtam |
| | | | | AM | SB | 11/9/99 | 13.72 | 32.2 | | | | tbli005G_i5slynam |
| | | | | PM | NB | 12/7/99 | 14.2 | 31.1 | 14.5 | 30.4 | 1 | tbli005G_5pm7n |
| | | | | PM | NB | 11/9/99 | 14.85 | 29.8 | | | | tbli005G_i5nevtpm |
| | | | | PM | SB | 12/7/99 | 7.2 | 61.4 | 7.3 | 60.4 | 2 | tbli005G_5pm7s |
| | | | | PM | SB | 11/9/99 | 7.45 | 59.3 | | | | tbli005G_i5slynpm |
| | 128th St to 204th St | Freeway - general lanes | 5.71 | AM | NB | 11/9/99 | 8.37 | 41.0 | | | | tbli005G_i5nevtam |
| | | | | PM | NB | 12/7/99 | 6.3 | 54.4 | 6.3 | 54.7 | 1 | tbli005G_5pm7n |
| | | | | PM | NB | 11/9/99 | 6.23 | 55.0 | | | | tbli005G_i5nevtpm |
| | | | | PM | SB | 12/7/99 | 5.95 | 57.6 | | | | tbli005G_5pm7s |

### DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 204th St to N 145th St | Freeway - general lanes | 6.16 | AM | NB | 11/10/99 | 7.27 | 50.9 | 6.6 | 56.9 | 18 | tbli005G_i5nlyam1 |
| | | | | AM | NB | 11/16/99 | 5.88 | 62.9 | | | | tbli005G_i5nlyam2 |
| | | | | AM | SB | 11/10/99 | 9.52 | 38.8 | 28.3 | 23.3 | 46 | tbli005G_i5sseam1 |
| | | | | AM | SB | 11/16/99 | 47.12 | 7.8 | | | | tbli005G_i5sseam2 |
| | | | | PM | NB | 11/16/99 | 14.38 | 25.7 | | | 27 | tbli005G_i5nlynpm |
| | | | | PM | SB | 11/10/99 | 6.55 | 56.5 | 7.7 | 49.0 | 22 | tbli005G_i5sseapm |
| | | | | PM | SB | 11/16/99 | 8.92 | 41.5 | | | | tbli005G_i5ssp2 |
| | 204th St to N 145th St | Freeway - HOV lanes | 6.16 | AM | NB | 12/15/99 | 5.37 | 68.9 | 5.5 | 67.8 | 0 | tbli005H_i515ham |
| | | | | AM | NB | 12/14/99 | 5.55 | 66.6 | | | | tbli005H_i5n14ham |
| | | | | AM | SB | 12/15/99 | 12.23 | 30.2 | 9.6 | 41.9 | 23 | tbli005H_i5s15ham |
| | | | | AM | SB | 12/14/99 | 6.9 | 53.6 | | | | tbli005H_i5s14ham |
| | | | | PM | NB | 12/14/99 | 12.08 | 30.6 | 9.5 | 41.8 | 23 | tbli005H_i514hpm |
| | | | | PM | NB | 12/15/99 | 6.97 | 53.1 | | | | tbli005H_i515hpm |
| | | | | PM | SB | 12/14/99 | 5.82 | 63.5 | 6.0 | 61.6 | 4 | tbli005H_i5s14hpm |
| | | | | PM | SB | 12/15/99 | 6.2 | 59.7 | | | | tbli005H_i5s15hpm |
| | N 145th St to N 45 St | Freeway - general lanes | 5.21 | AM | NB | 11/10/99 | 5.1 | 61.3 | 5.2 | 60.0 | 3 | tbli005G_i5nlyam1 |
| | | | | AM | NB | 11/16/99 | 5.33 | 58.7 | | | | tbli005G_i5nlyam2 |
| | | | | AM | SB | 11/10/99 | 10.83 | 28.9 | 9.0 | 36.0 | 14 | tbli005G_i5sseam1 |
| | | | | AM | SB | 11/16/99 | 7.25 | 43.1 | | | | tbli005G_i5sseam2 |
| | | | | PM | NB | 11/16/99 | 21.02 | 14.9 | 16.3 | 21.0 | 12 | tbli005G_i5nlynpm |
| | | | | PM | NB | 11/10/99 | 11.55 | 27.1 | | | | tbli005G_i5n1sepm |
| | | | | PM | SB | 11/10/99 | 17.02 | 18.4 | 12.1 | 31.0 | 25 | tbli005G_i5sseapm |
| | | | | PM | SB | 11/16/99 | 7.17 | 43.6 | | | | tbli005G_i5ssp2 |
| | N 45th St to Denny Way | Freeway - general lanes | 3.19 | AM | NB | 11/10/99 | 3.28 | 58.3 | 6.0 | 40.1 | 37 | tbli005G_i5nlyam1 |
| | | | | AM | NB | 11/16/99 | 8.77 | 21.8 | | | | tbli005G_i5nlyam2 |
| | | | | AM | SB | 11/10/99 | 4.73 | 40.4 | 4.6 | 41.5 | 2 | tbli005G_i5sseam1 |
| | | | | AM | SB | 11/16/99 | 4.5 | 42.5 | | | | tbli005G_i5sseam2 |
| | | | | PM | NB | 11/2/99 | 4.82 | 39.7 | 8.8 | 27.4 | 25 | tbli005G_sr5nbp |
| | | | | PM | NB | 11/16/99 | 12.7 | 15.1 | | | | tbli005G_i5nlynpm |
| | | | | PM | SB | 11/10/99 | 8.43 | 22.7 | 8.5 | 22.6 | 0 | tbli005G_i5sseapm |
| | | | | PM | SB | 11/16/99 | 8.5 | 22.5 | | | | tbli005G_i5ssp2 |
| | NE Northgate Way to I-405 | Freeway - HOV lanes | 9.87 | AM | NB | 12/15/99 | 9.15 | 64.7 | 9.2 | 64.6 | 0 | tbli005H_i515ham |
| | | | | AM | NB | 12/14/99 | 9.18 | 64.5 | | | | tbli005H_i5n14ham |

## DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | AM | SB | 12/14/99 | 11.12 | 53.2 | | | | tbli005H_i5s14ham |
| | | | | PM | NB | 12/14/99 | 16.32 | 36.3 | 13.9 | 44.1 | 16 | tbli005H_i514hpm |
| | | | | PM | NB | 12/15/99 | 11.42 | 51.8 | | | | tbli005H_i515hpm |
| | | | | PM | SB | 12/15/99 | 11.93 | 49.6 | | | | tbli005H_i5s15hpm |
| | I-405 to SR 526 | Freeway - HOV lanes | 6.70 | AM | NB | 12/15/99 | 6.08 | 66.1 | | | | tbli005H_i515ham |
| | | | | AM | SB | 12/15/99 | 6.63 | 60.6 | 6.4 | 62.5 | 4 | tbli005H_i5s15ham |
| | | | | AM | SB | 12/14/99 | 6.25 | 64.3 | | | | tbli005H_i5s14ham |
| | | | | PM | NB | 12/14/99 | 7.85 | 51.2 | 7.1 | 57.0 | 12 | tbli005H_i514hpm |
| | | | | PM | NB | 12/15/99 | 6.40 | 62.8 | | | | tbli005H_i515hpm |
| | | | | PM | SB | 12/14/99 | 6.28 | 64.0 | 6.2 | 64.5 | 1 | tbli005H_i5s14hpm |
| | | | | PM | SB | 12/15/99 | 6.18 | 65.0 | | | | tbli005H_i5s15hpm |
| I-90 | Rainier Ave S to I-405 | Freeway - general lanes | 6.56 | AM | EB | 11/2/99 | 11.08 | 35.5 | 9.4 | 43.3 | 16 | tbli090G_i90eam |
| | | | | AM | EB | 10/27/99 | 7.7 | 51.1 | | | | tbli090G_i90eamhh |
| | | | | AM | WB | 10/27/99 | 6.97 | 56.5 | 7.8 | 51.3 | 10 | tbli090G_i90w1am |
| | | | | AM | WB | 12/7/99 | 8.53 | 46.2 | | | | tbli090G_90dam7w |
| | | | | PM | EB | 11/3/99 | 10.45 | 37.7 | 10.0 | 39.3 | 3 | tbli090G_113i90e |
| | | | | PM | EB | 10/27/99 | 9.63 | 40.9 | | | | tbli090G_i90e2pm |
| | | | | PM | WB | 10/27/99 | 13.08 | 30.1 | 10.1 | 42.8 | 25 | tbli090G_i90wpm |
| | | | | PM | WB | 11/2/99 | 7.1 | 55.5 | | | | tbli090G_sr90wbp |
| | I-405 to Front Street | Freeway - general lanes | 7.24 | AM | EB | 11/2/99 | 7.13 | 60.9 | 7.3 | 59.5 | 3 | tbli090G_i90eam |
| | | | | AM | EB | 10/27/99 | 7.47 | 58.1 | | | | tbli090G_i90eamhh |
| | | | | AM | WB | 12/7/99 | 8.2 | 53.0 | | | | tbli090G_90dam7w |
| | | | | PM | EB | 10/27/99 | 7.72 | 56.3 | 7.9 | 55.2 | 2 | tbli090G_i90e2pm |
| | | | | PM | EB | 11/3/99 | 8.02 | 54.1 | | | | tbli090G_113i90e |
| | | | | PM | WB | 10/27/99 | 7.18 | 60.5 | 9.1 | 49.8 | 21 | tbli090G_i90wpm |
| | | | | PM | WB | 11/2/99 | 11.1 | 39.1 | | | | tbli090G_sr90wbp |

## DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bellevue Way SE to NW Sammamish | Freeway - HOV lanes | 6.55 | AM | EB | 12/7/99 | 6.40 | 61.4 | | | | tbli090H_90ham7e |
| | | | | PM | WB | 12/8/99 | 6.80 | 57.8 | 7.0 | 56.3 | 3 | tbli090H_h90wp18_PosnPnt |
| | | | | PM | WB | 12/8/99 | 7.17 | 54.8 | | | | tbli090H_hs90wp28_PosnPn |
| S 180th St/ SW 43rd St/ Carr Rd SE | W Valley Rd to 108th Ave SE | Arterial | 2.38 | AM | EB | 11/4/99 | 9.23 | 15.4 | 7.2 | 21.5 | 12 | tbls180G_s180am1 |
| | | | | AM | EB | 11/9/99 | 5.17 | 27.6 | | | | tbls180G_s180eam |
| | | | | AM | WB | 11/9/99 | 8.05 | 17.7 | | | | tbls180G_s180wam |
| | | | | PM | EB | 11/11/99 | 10.33 | 13.8 | 11.0 | 13.2 | 1 | tbls180G_s180epm |
| | | | | PM | EB | 11/3/99 | 9.72 | 14.7 | | | | tbls180G_s180pm11 |
| | | | | PM | EB | 11/3/99 | 12.88 | 11.1 | | | | tbls180G_s180pm21 |
| | | | | PM | WB | 11/3/99 | 7.28 | 19.6 | 8.9 | 16.4 | 6 | tbls180G_s180pm12 |
| | | | | PM | WB | 11/3/99 | 9.10 | 15.7 | | | | tbls180G_s180pm22 |
| | | | | PM | WB | 11/11/99 | 10.30 | 13.8 | | | | tbls180G_s180wpm |
| SR 3/SR 16 | Pacific Ave to Sedgewick Rd | Arterial | 9.30 | AM | NB | 10/26/99 | 15.75 | 35.4 | | | | tblsr003G_pto2bram |
| | | | | AM | SB | 10/26/99 | 13.77 | 40.5 | | | | tblsr003G_br2ptoam |
| | | | | PM | NB | 10/20/99 | 15.53 | 35.9 | 14.4 | 39.0 | 6 | tblsr003G_fif2brpm |
| | | | | PM | NB | 10/26/99 | 13.23 | 42.2 | | | | tblsr003G_pto2brpm |
| | | | | PM | SB | 10/26/99 | 23.20 | 24.0 | | | | tblsr003G_br2ptopm |
| SR 16/I-5 | Wollochet Dr. NW to 12th St | Freeway - general lanes | 6.26 | AM | NB | 10/26/99 | 7.13 | 52.7 | 11.0 | 39.7 | 31 | tblsr016G_f2gigam |
| | | | | AM | NB | 10/19/99 | 17.63 | 21.3 | | | | tblsr016G_fgig |
| | | | | AM | NB | 10/21/99 | 8.33 | 45.1 | | | | tblsr016G_fife2gig |
| | | | | AM | SB | 10/26/99 | 17.20 | 21.9 | | | | tblsr016G_gig2fam |
| | | | | PM | NB | 10/20/99 | 23.90 | 15.7 | 47.8 | 10.5 | 11 | tblsr016G_f2gh2p2b |
| | | | | PM | NB | 10/19/99 | 71.63 | 5.2 | | | | tblsr016G_f2gigpm |
| | | | | PM | SB | 10/21/99 | 6.45 | 58.3 | | | | tblsr016G_gig2fpm |

## DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 12th St to SR 99 | Freeway - general lanes | 4.82 | AM | NB | 10/26/99 | 9.63 | 30.0 | 28.5 | 18.1 | 24 | tblsr016G_f2gigam |
|  |  |  |  | AM | NB | 10/21/99 | 47.40 | 6.1 |  |  |  | tblsr016G_fife2gig |
|  |  |  |  | AM | SB | 10/26/99 | 11.33 | 25.5 |  |  |  | tblsr016G_gig2fam |
|  |  |  |  | PM | NB | 10/19/99 | 36.83 | 7.8 | 23.5 | 18.1 | 21 | tblsr016G_f2gigpm |
|  |  |  |  | PM | NB | 10/20/99 | 10.22 | 28.3 |  |  |  | tblsr016G_f2gh2p2b |
|  |  |  |  | PM | SB | 10/21/99 | 10.15 | 28.5 |  |  |  | tblsr016G_gig2fpm |
| SR 520 | Montlake to Bellevue Way | Freeway - general lanes | 5.03 | AM | EB | 11/3/99 | 9.82 | 30.8 |  |  |  | tblsr520G_113a520e |
|  |  |  |  | AM | WB | 10/20/99 | 8.65 | 34.9 | 9.2 | 32.8 | 4 | tbli405G_sr5204052 |
|  |  |  |  | AM | WB | 11/3/99 | 9.82 | 30.8 |  |  |  | tblsr520G_113a520w |
|  | Bellevue Way to East of I-405 | Freeway - general lanes | 0.95 | PM | WB | 11/2/99 | 2.88 | 19.7 |  |  |  | tblsr520G_112p520w |
|  | East of I-405 to SR 202 | Freeway - general lanes | 6.13 | PM | EB | 11/2/99 | 6.65 | 55.3 |  |  |  | tblsr520G_112p520e |
|  |  |  |  | PM | WB | 11/2/99 | 4.57 | 80.5 |  |  |  | tblsr520G_112p520w |
| SR 522 | I-5 Ramp to 68th St | Arterial | 7.07 | AM | EB | 11/2/99 | 14.67 | 28.9 | 12.7 | 33.8 | 9 | tblsr522G_i522e2am |
|  |  |  |  | AM | EB | 11/3/99 | 12.43 | 34.1 |  |  |  | tblsr522G_sr522na2 |
|  |  |  |  | AM | EB | 11/3/99 | 11.07 | 38.3 |  |  |  | tblsr522G_sr522nba |
|  |  |  |  | AM | WB | 11/3/99 | 15.43 | 27.5 |  |  |  | tblsr522G_sr522sba |
|  |  |  |  | PM | EB | 10/28/99 | 18.75 | 22.6 | 17.0 | 25.1 | 1 | tblsr522G_522npm2 |
|  |  |  |  | PM | EB | 11/2/99 | 15.32 | 27.7 |  |  |  | tblsr522G_i522epm |
|  |  |  |  | PM | WB | 11/2/99 | 18.72 | 22.6 | 28.1 | 17.0 | 11 | tblsr522G_i522wpm |
|  |  |  |  | PM | WB | 10/28/99 | 37.48 | 11.3 |  |  |  | tblsr522G_522nbpm1 |
|  | 68th St to SR 202 | Arterial | 5.47 | AM | NB | 11/3/99 | 8.82 | 37.2 | 8.1 | 40.7 | 7 | tblsr522G_sr522na2 |
|  |  |  |  | AM | NB | 11/3/99 | 7.42 | 44.3 |  |  |  | tblsr522G_sr522nba |
|  |  |  |  | AM | SB | 11/3/99 | 9.78 | 33.6 | 8.4 | 40.1 | 13 | tblsr522G_sr522sa2 |
|  |  |  |  | AM | SB | 11/3/99 | 7.05 | 46.6 |  |  |  | tblsr522G_sr522sba |
|  |  |  |  | PM | EB | 11/2/99 | 7.03 | 46.7 | 13.2 | 29.8 | 30 | tblsr522G_i522epm |
|  |  |  |  | PM | EB | 10/28/99 | 12.42 | 26.4 |  |  |  | tblsr522G_522nbpm1 |
|  |  |  |  | PM | SB | 10/28/99 | 20.03 | 16.4 |  |  |  | tblsr522G_522spm3 |
|  |  |  |  | PM | WB | 11/2/99 | 9.9 | 33.2 |  |  |  | tblsr522G_i522wpm |
| SR 524 | SR 99 to SR 527 SE | Arterial | 5.91 | AM | EB | 12/8/99 | 14.2 | 25.0 |  |  |  | tblsr524G_5248ame |

# DETAILED TRAVEL TIME  RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | AM | WB | 12/8/99 | 15.2 | 23.3 | | | | tblsr524G_524am8w |
| | | | | PM | EB | 11/11/99 | 19.92 | 17.8 | 18.6 | 19.6 | 10 | tblsr524G_524epm |
| | | | | PM | EB | 12/7/99 | 18.72 | 18.9 | | | | tblsr524G_524pm7e |
| | | | | PM | EB | 12/8/99 | 22.1 | 16.0 | | | | tblsr524G_524pm8e |
| | | | | PM | EB | 10/20/99 | 13.75 | 25.8 | | | | tblsr524G_sr524per |
| | | | | PM | WB | 12/7/99 | 19.85 | 17.9 | 18.8 | 18.9 | 2 | tblsr524G_524pm7w |
| | | | | PM | WB | 12/8/99 | 17.82 | 19.9 | | | | tblsr524G_528pm8w |
| SR 99 | Battery St. to 45th St. | Arterial | 3.04 | AM | SB | 11/10/99 | 3.57 | 51.1 | 3.6 | 50.9 | 0 | tblsr099G_111099s1 |
| | | | | AM | SB | 10/19/99 | 3.6 | 50.7 | | | | tblsr099G_sr99ap |
| | | | | PM | SB | 11/4/99 | 3.72 | 49.1 | 6.9 | 33.6 | 31 | tblsr099G_11499ps |
| | | | | PM | SB | 11/9/99 | 10.08 | 18.1 | | | | tblsr099G_119p99s1 |
| | 45th St. to 105th St. | Arterial | 2.99 | AM | NB | 11/10/99 | 6.1 | 29.4 | | | | tblsr099G/-1110a99n |
| | | | | AM | SB | 11/10/99 | 7.87 | 22.8 | 6.5 | 28.7 | 12 | tblsr099G_111099s2 |
| | | | | AM | SB | 10/19/99 | 5.18 | 34.6 | | | | tblsr099G_sr99ap |
| | | | | PM | SB | 11/4/99 | 8.95 | 20.0 | 13.9 | 14.8 | 11 | tblsr099G//-11499ps |
| | | | | PM | SB | 11/9/99 | 18.92 | 9.5 | | | | tblsr099G_119p99s1 |
| | 105th St to SR 524 | Arterial | 8.36 | AM | NB | 11/10/99 | 25.35 | 19.8 | | | | tblsr099G_1110a99n |
| | | | | AM | SB | 11/10/99 | 28.75 | 17.5 | 27.9 | 18.1 | 2 | tblsr099G_111099s2 |
| | | | | AM | SB | 10/19/99 | 26.97 | 18.6 | | | | tblsr099G_sr99ap |
| | | | | PM | NB | 11/9/99 | 36.25 | 13.8 | | | | tblsr099G_119p99n1 |
| | | | | PM | SB | 11/4/99 | 30.32 | 16.6 | 35.8 | 14.4 | 4 | tblsr099G_11499ps |
| | | | | PM | SB | 11/9/99 | 41.28 | 12.2 | | | | tblsr099G_119p99s1 |
| | Alaskan Viaduct to E Marginal Way | Arterial | 2.51 | AM | NB | 10/27/99 | 8.47 | 17.8 | 9.3 | 16.2 | 3 | tblsr099G_fed2sea |
| | | | | AM | NB | 11/9/99 | 10.22 | 14.7 | | | | tblsr099G_sr99an7 |
| | | | | AM | SB | 10/19/99 | 7.32 | 20.5 | | | | tblsr099G_sr99ap |
| | | | | PM | NB | 11/9/99 | 12 | 12.5 | | | | tblsr099G_sr99np1 |
| | | | | PM | SB | 11/4/99 | 8.5 | 17.7 | | | | tblsr099G_s99pm |
| | E Marginal Way to S 188th St | Arterial | 7.87 | AM | NB | 12/8/99 | 49.95 | 9.5 | 30.5 | 18.5 | 16 | tblsr099G_99am8an |
| | | | | AM | NB | 10/27/99 | 18.68 | 25.3 | | | | tblsr099G_fed2sea |
| | | | | AM | NB | 11/11/99 | 22.85 | 20.7 | | | | tblsr099G_n99fwam |
| | | | | AM | SB | 11/11/99 | 25.33 | 18.6 | 20.7 | 24.1 | 11 | tblsr099G_s99wam |
| | | | | AM | SB | 10/19/99 | 15.97 | 29.6 | | | | tblsr099G_sr99ap |

# DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | PM | NB | 11/10/99 | 17.85 | 26.5 | 16.6 | 28.6 | 4 | tblsr099G_n99fwpm1 |
| | | | | PM | NB | 11/9/99 | 15.37 | 30.7 | | | | tblsr099G_sr99np1 |
| | | | | PM | SB | 11/4/99 | 20.95 | 22.5 | 21.6 | 21.9 | 1 | tblsr099G_s99pm |
| | | | | PM | SB | 11/10/99 | 22.23 | 21.2 | | | | tblsr099G_s99pm1 |
| | S 188th St to Kent Des Moines Rd | Arterial | 2.88 | AM | NB | 10/27/99 | 5.27 | 32.7 | 10.4 | 21.6 | 24 | tblsr099G_fed2sea |
| | | | | AM | NB | 11/4/99 | 20.77 | 8.3 | | | | tblsr099G_n99ampt |
| | | | | AM | NB | 11/11/99 | 6.75 | 25.6 | | | | tblsr099G_n99fwam |
| | | | | AM | NB | 11/9/99 | 8.67 | 19.9 | | | | tblsr099G_sr99na1 |
| | | | | AM | SB | 11/11/99 | 6.45 | 26.8 | 17.4 | 16.4 | 21 | tblsr099G_s99wam |
| | | | | AM | SB | 10/19/99 | 28.4 | 6.1 | | | | tblsr099G_sr99ap |
| | | | | PM | NB | 11/10/99 | 7.03 | 24.5 | 7.4 | 23.3 | 2 | tblsr099G_n99fwpm1 |
| | | | | PM | NB | 11/9/99 | 7.8 | 22.1 | | | | tblsr099G_sr99np1 |
| | | | | PM | SB | 11/3/99 | 10.32 | 16.7 | 12.0 | 15.0 | 6 | tblsr099G_sr99sbp2 |
| | | | | PM | SB | 11/4/99 | 9.98 | 17.3 | | | | tblsr099G_s99pm |
| | | | | PM | SB | 11/10/99 | 15.62 | 11.0 | | | | tblsr099G_s99pm1 |
| | Kent Des Moines Rd to S 320th St | Arterial | 5.54 | AM | NB | 11/9/99 | 16.83 | 19.7 | 14.5 | 25.2 | 20 | tblsr099G_sr99na1 |
| | | | | AM | NB | 10/27/99 | 11.43 | 29.1 | | | | tblsr099G_fed2sea |
| | | | | AM | NB | 11/4/99 | 20.55 | 16.2 | | | | tblsr099G_n99ampt |
| | | | | AM | NB | 11/11/99 | 9.32 | 35.7 | | | | tblsr099G_n99fwam |
| | | | | AM | SB | 11/11/99 | 9 | 36.9 | 11.7 | 30.1 | 14 | tblsr099G_s99wam |
| | | | | AM | SB | 10/19/99 | 14.32 | 23.2 | | | | tblsr099G_sr99ap |
| | | | | PM | NB | 11/10/99 | 10.92 | 30.4 | 12.2 | 27.5 | 6 | tblsr099G_n99fwpm1 |
| | | | | PM | NB | 11/9/99 | 13.52 | 24.6 | | | | tblsr099G_sr99np1 |
| | | | | PM | SB | 11/4/99 | 13.02 | 25.5 | 15.8 | 21.4 | 6 | tblsr099G_s99pm |
| | | | | PM | SB | 11/10/99 | 17.3 | 19.2 | | | | tblsr099G_s99pm1 |
| | | | | PM | SB | 11/3/99 | 17.03 | 19.5 | | | | tblsr099G_sr99sbp2 |

## DETAILED TRAVEL TIME RUN DATA

| Corridor | Segment | Facility Type | Length (miles) | Peak Period | Dir | Run Date | Travel Time (min.) | Travel Speed (mph) | Avg. Travel Time (min.) | Avg. Travel Speed (mph.) | Speed Range (mph) | Run Name |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I-405 | I-5 to I-90 | Freeway - HOV lanes | 11.13 | AM | NB | 12/9/99 | 36.5 | 18.3 | 27.6 | 27.0 | 17 | tbli405H_405ha9n |
| | | | | AM | NB | 12/9/99 | 18.7 | 35.7 | | | | tbli405H_405nha1 |
| | | | | AM | SB | 12/9/99 | 11 | 60.7 | 11.4 | 58.6 | 4 | tbli405H_405ha9s |
| | | | | AM | SB | 12/9/99 | 11.82 | 56.5 | | | | tbli405H_h405as19 |
| | | | | PM | NB | 12/9/99 | 11.7 | 57.1 | 12.0 | 56.2 | 10 | tbli405H_405hp9n |
| | | | | PM | NB | 12/9/99 | 13.17 | 50.7 | | | | tbli405H_405n2hp9 |
| | | | | PM | NB | 12/9/99 | 10.98 | 60.8 | | | | tbli405H_h405np19 |
| | | | | PM | SB | 12/9/99 | 15 | 44.5 | | | | tbli405H_405hp9s |
| | I-90 to SR 520 | Freeway - HOV lanes | 3.73 | AM | NB | 12/9/99 | 22.3 | 10.0 | 22.5 | 10.0 | 0 | tbli405H_405ha9n |
| | | | | AM | NB | 12/9/99 | 22.65 | 9.9 | | | | tbli405H_405nha1 |
| | | | | AM | SB | 12/9/99 | 3.83 | 58.5 | 3.9 | 57.6 | 3 | tbli405H_405s2a9 |
| | | | | AM | SB | 12/9/99 | 4 | 56.0 | | | | tbli405H_405ha9s |
| | | | | AM | SB | 12/9/99 | 3.85 | 58.2 | | | | tbli405H_h405as19 |
| | | | | PM | NB | 12/9/99 | 3.95 | 56.7 | 3.8 | 58.9 | 4 | tbli405H_405hp9n |
| | | | | PM | NB | 12/9/99 | 3.77 | 59.4 | | | | tbli405H_h405np19 |
| | | | | PM | NB | 12/9/99 | 3.7 | 60.6 | | | | tbli405H_405n2hp9 |
| | | | | PM | SB | 12/9/99 | 4.35 | 51.5 | 4.5 | 50.5 | 5 | tbli405H_405hp9s |
| | | | | PM | SB | 12/9/99 | 4.73 | 47.4 | | | | tbli405H_405s2ph9 |
| | | | | PM | SB | 12/9/99 | 4.27 | 52.5 | | | | tbli405H_405sph9 |
| | SR 520 to SR 527 | Freeway - HOV lanes | 11.92 | AM | NB | 12/9/99 | 11.3 | 63.3 | | | | tbli405H_405ha9n |
| | | | | AM | SB | 12/9/99 | 18.3 | 39.1 | 16.9 | 42.7 | 7 | tbli405H_405ha9s |
| | | | | AM | SB | 12/9/99 | 15.48 | 46.2 | | | | tbli405H_h405as19 |
| | | | | PM | NB | 12/9/99 | 17.75 | 40.3 | | | | tbli405H_405hp9n |
| | | | | PM | SB | 12/9/99 | 11.05 | 64.7 | | | | tbli405H_405hp9s |