3 TEST VEHICLE TECHNIQUES

The test vehicle technique has been used for travel time data collection since the late 1920s. Traditionally, this technique has involved the use of a data collection vehicle within which an observer records cumulative travel time at predefined checkpoints along a travel route. This information is then converted to travel time, speed, and delay for each segment along the survey route. There are several different methods for performing this type of data collection, depending upon the instrumentation used in the vehicle and the driving instructions given to the driver. Since these vehicles are instrumented and then sent into the field for travel time data collection, they are sometimes referred to as "active" test vehicles. Conversely, "passive" ITS probe vehicles are vehicles that are already in the traffic stream for purposes other than data collection. ITS probe vehicle techniques are discussed in Chapter 5.

This chapter describes three levels of instrumentation used to measure travel time with a test vehicle:

- **Manual** - manually recording elapsed time at predefined checkpoints using a passenger in the test vehicle;

- **Distance Measuring Instrument (DMI)** - determining travel time along a corridor based upon speed and distance information provided by an electronic DMI connected to the transmission of the test vehicle; and

- **Global Positioning System (GPS)** - determines test vehicle position and speed by using signals from the Department of Defense (DOD) system of earth-orbiting satellites.

Historically, the manual method has been the most commonly used travel time data collection technique. This method requires a driver and a passenger to be in the test vehicle. The driver operates the test vehicle while the passenger records time information at predefined checkpoints. Technology has automated the manual method with the use of an electronic DMI. The DMI is connected to a portable computer in the test vehicle and receives pulses at given intervals from the transmission of the vehicle. Distance and speed information are then determined from these pulses.

GPS has become the most recent technology to be used for travel time data collection. A GPS receiver is connected to a portable computer and collects the latitude and longitude information that enables tracking of the test vehicle. Each of these test vehicle techniques is described in detail in the following sections of this chapter. The following elements are included for each technique: overview, advantages and disadvantages, cost and equipment requirements, data collection instructions, data reduction and quality control, and previous experiences.

Since the driver of the test vehicle is a member of the data collection team, driving styles and behavior can be controlled to match desired driving behavior. The following are three common test vehicle driving styles (1):

- *Average car* - test vehicle travels according to the driver's judgement of the average speed of the traffic stream;

- *Floating car* - driver "floats" with the traffic by attempting to safely pass as many vehicles as pass the test vehicle; and

- *Maximum car* - test vehicle is driven at the posted speed limit unless impeded by actual traffic conditions or safety considerations.

The floating car driving style is the most commonly referenced. In practice, however, drivers will likely adopt a hybrid of the floating car and average car because of the inherent difficulties of keeping track of passed and passing vehicles in high traffic volume conditions

IMPORTANT ☞ Most travel time studies incorporate a hybrid of the floating car and average car driving styles. Differences between individual test drivers will probably account for more variation than exist between these two driving styles.

3.0.1 General Advantages and Disadvantages

Test vehicle techniques have the following **advantages:**

- Provides for the determination of driving styles (e.g., "floating car"), which provides consistent data collection;

- Advanced test vehicle techniques (e.g., DMI or GPS use) result in detailed data that cover the entire study corridor; and

- Relatively low initial cost.

Test vehicle techniques have the following **disadvantages:**

- Sources of possible error from either human or electric sources that require adequate quality control;

- Advanced and detailed data collection techniques (e.g., every second) can provide data storage difficulties; and

- The travel time estimates for the corridor are based on only one vehicle that is in the traffic stream.

Detailed advantages and disadvantages of the three instrumentation levels for the test vehicle technique are described in subsequent sections of this chapter. Table 3-1 provides a relative comparison of the three different instrumentation levels.

Table 3-1. Comparison of Test Vehicle Travel Time Data Collection Techniques

Instrumentation Level	Costs			Skill Level		Level of Data Detail	Data Accuracy	Automation Potential
	Capital	Data Collection	Data Reduction	Data Collection	Data Reduction			
Manual-Pen and Paper	Low	Moderate	High	Low	Moderate	Low	Low	Low
Tape Recorder	Low	Low	High	Low	Moderate	Low	Low	Low
Portable Computer	Moderate	Low	Moderate	Moderate	Moderate	Low	Moderate	Moderate
Distance Measuring Instrument (DMI)	High	Low	Low	Moderate	Low	High	Moderate	High
Global Positioning System (GPS)	High	Low	Moderate	Moderate	High	High	High	High

Note: Rating scale is relative among the instrumentation levels shown: [high, moderate, low].

3.0.2 Sample Sizes

Sample size requirements for the test vehicle technique dictate the number of "runs" that must be performed for a given roadway during the time period(s) of interest. The use of minimum samples sizes, or a minimum number of travel time runs, ensures that the average travel time obtained from the test vehicle is within a specified error range of the true average travel time for the entire vehicle population. The standard sample size equation is shown as Equation 3-1 (2). Using the relationships in Equations 3-2 and 3-3, Equation 3-4 is derived for use by practitioners in computing sample sizes for test vehicle travel time runs.

$$Sample\ Size,\ n = \left(\frac{t \times s}{\varepsilon} \right)^2 \qquad (3\text{-}1)$$

where: t = t-statistic from Student's t distribution for specified confidence level;
s = standard deviation of travel time; and
ε = maximum specified allowable error.

$$Coefficient\ of\ Variation,\ c.v. = \frac{s}{\bar{x}} \qquad (3\text{-}2) \qquad\qquad Relative\ Error,\ e = \frac{\varepsilon}{\bar{x}} \qquad (3\text{-}3)$$

where: $\bar{x}$ = mean travel time

$$Sample\ Size,\ n = \left(\frac{t \times s}{\varepsilon} \right)^2 = \left(\frac{t \times (c.v. \times \bar{x})}{(e \times \bar{x})} \right)^2 = \left(\frac{t \times c.v.}{e} \right)^2 \qquad (3\text{-}4)$$

If sample sizes approach 30 or more (uncommon for test vehicle runs), the normal distribution can be used in place of the Student's t distribution and Equation 3-5 is applicable.

$$Sample\ Size,\ n = \left(\frac{z \times c.v.}{e} \right)^2 \quad \text{if estimated sample size is greater than } 30 \qquad (3\text{-}5)$$

As shown in Equations 3-4 and 3-5, minimum sample sizes are based upon three parameters:

- **T-statistic, t -** value from the Student's t distribution for (n-1) degrees of freedom. The t-statistic is based upon the specified confidence level (two-tailed test) in the travel time estimate. Because the degrees of freedom for the t-statistic rely on a sample size, n, an initial sample size estimate must be assumed. Iterative calculations should be used to provide better estimates for the degrees of freedom. If sample sizes approach 30 or more, a z-statistic from the normal distribution may be substituted for the t-statistic.

- **Coefficient of variation, c.v.** - the relative variability in the travel times, expressed as a percentage (%). The c.v. values can be calculated from empirical data using

Equation 3-2, or approximate values of 9 to 17 percent can be used from other studies (Table 3-2) (2,3,4).

- **Relative allowable error, e** - the relative permissible error in the travel time estimate, expressed as a percentage (%). The relative error is specified by the study designer and will depend upon the uses of the travel time data. Commonly specified relative errors are ± 5 percent for operations and evaluation studies and ± 10 percent for planning and policy-level studies (3).

Table 3-2. Coefficients of Variation for the Test Vehicle Technique on Freeways and Arterial Streets

Freeways		Arterial Streets	
Average Daily Traffic (ADT) Volume per lane	Average Coefficient of Variation (%)	Traffic Signal Density (signals per database)	Average Coefficient of Variation (%)
Less than 15,000	9	Less than 3	9
15,000 to 20,000	11	3 to 6	12
Greater than 20,000	17	Greater than 6	15

Source: adapted from reference (3).

Coefficients of variation for travel times will range depending upon the physical and traffic control characteristics of the roadway (e.g., number of signals, signal progression, ramp access spacing) and the traffic conditions (e.g., free-flow versus stop-and-go congestion). Research of the test vehicle method in 1949 by Berry and Green produced coefficients of variation for urban streets ranging from 9 to 16 percent (5). Subsequent studies found coefficients of variation ranging from 5 to 17 percent (6). Several other empirical study results have indicated that coefficients of variation are on the order of 8 to 17 percent (2). A recent National Cooperative Highway Research Program (NCHRP) study confirmed these estimates of variation for varying conditions on freeways and arterial streets, as shown in Table 3-2 (3). These coefficient of variation estimates should be checked against data that is collected to ensure the validity of estimated sample sizes.

Therefore, minimum sample sizes or number of travel time runs can be calculated using Equation 3-4 and Table 3-2. The t-statistic (or z-statistic for samples greater than 30) can be obtained from most basic statistics texts. The permitted relative error should be based upon the intended uses of the travel time data. Tables 3-3 and 3-4 show minimum sample sizes for various combinations of confidence level and permitted relative error.

Table 3-3. Illustrative Test Vehicle Sample Sizes on Freeways

Average Daily Traffic (ADT) Volume per lane	Average Coefficient of Variation, (%) Table 3-2	Sample Sizes (iterative calculations using Equation 3-4)		
		90% Confidence, ± 10 % Error	95% Confidence, ± 10 % Error	95% Confidence, ± 5 % Error
Less than 15,000	9	5	6	15
15,000 to 20,000	11	6	8	21
Greater than 20,000	17	10	14	47

Source: adapted from reference (3).

Table 3-4. Illustrative Test Vehicle Sample Sizes on Arterial Streets

Traffic Signal Density (signals per mile)	Average Coefficient of Variation, (%) Table 3-2	Sample Sizes (iterative calculations using Equation 3-4)		
		90% Confidence, ± 10 % Error	95% Confidence, ± 10 % Error	95% Confidence, ± 5 % Error
Less than 3	9	5	6	15
3 to 6	12	6	8	25
Greater than 6	15	9	12	37

Source: adapted from reference (3).

Many agencies perform the maximum number of test vehicle runs that is practical given available data collection budgets (typically 3 to 6 runs per route). While this is a common practice, it should be recognized that the potential accuracy of the data falls at or below the lowest accuracy range shown in Tables 3-3 and 3-4 (90 percent confidence level, ±10 percent error).

IMPORTANT ☞ After the minimum number of travel time runs is determined, these runs should be evenly distributed throughout the data collection time period and over several different weekdays.

To evenly distribute the travel time runs, some agencies use approximate headways between test vehicles (e.g., 30-minute headways) as a way to distribute runs evenly throughout a time period. The length of the travel time run and the number of test vehicles will influence the minimum headways that can be achieved for any particular day.

The Institute of Transportation Engineers' (ITE) *Manual of Transportation Engineering Studies* (1) contains travel time data collection guidelines, and suggests the calculation of sample sizes based upon the average range in running speed (as opposed to the standard deviation or coefficient of variation). The average range is supposedly used in sample size calculations to determine, in the field, whether additional runs were necessary beyond a minimum that has already been collected.

Subsequent research by Strickland (7) and Quiroga and Bullock (8) questioned the validity of ITE's sample size guidelines, suggesting that actual sample sizes using average ranges should be much higher. Both research efforts use the average range as an estimator for the standard deviation in the sample size equation. The authors assert that the range is a simpler, more intuitive statistical measure. The ITE guidelines and this recent research suggest conducting several travel time runs, then computing range values and corresponding travel times. There are several problems with this suggested approach of using ranges to compute sample sizes:

- One cannot accurately budget or plan travel time data collection because the necessary sample sizes (calculated using range) are not known until data collection has already begun;
- Standard deviation is considered a more statistically robust measure of variability, which is the factor that directly controls minimum sample sizes;
- Sample size calculations using standard deviation are just as easy using range, and can easily be automated using computer spreadsheet or database programs; and
- Sample sizes should be designed and monitored by a study manager, not data collection personnel in the field, given each person's typical experience.

3.0.3 Data Collection Considerations

This section describes data collection, reduction, and quality control considerations for the test vehicle technique. Consideration of these elements will aid in a successful data collection effort.

General Considerations

- **Data collection forms** - Many travel time data collection forms are available and the form used should fit the needs of the study. Examples of these forms are shown later in Section 3.1.4 of this chapter. Not only does the form provide a medium for recording data, it serves as a guide for the test vehicle driver to follow. Common landmarks are often provided on the data collection forms. These landmarks provide the driver with a highly visible reference for a checkpoint (e.g., overpasses, businesses). Landmarks are especially helpful for large travel time studies in which drivers may not be familiar with each route or for freeway facilities where high speeds and inadequately marked cross streets cause difficulty in determining the proper checkpoint.

- **Extra supplies** - Ensure that additional supplies are available to alleviate the need to reschedule data collection activities. Inexpensive items such as extra pens or pencils, data collection forms, extra stopwatches or batteries are all relatively inexpensive when compared to having to reschedule and recollect the data for a study.

- **Fuel vehicles** - Most data collection is conducted during the morning and evening peak periods. This typically requires some staff to work extensive hours (i.e., start work early or stay late). Drivers should fill the vehicles with fuel at the end of the data collection period. Missed runs or late starts can be avoided and the potential for makeup runs are reduced.

- **Field communication** - Inevitably, there are always questions about the data collection technique, incidents, and technical or mechanical problems. Most of these questions could be immediately answered by the data collection supervisor. The use of cellular phones or pay phones can provide valuable guidance to field personnel. Drivers and observers should be provided with the supervisor's phone number(s) and encouraged to call if they have questions. A couple minutes of the supervisor's time can avoid the cost and time of rescheduling data collection.

- **Report problems** - With any data collection effort, problems may occur. Major accidents and anomalies (e.g., trains, signal malfunction, flooding) will have a great effect on travel time and should be reported directly to the supervisor. Equipment or mechanical problems are also extremely important. In addition, broken or faulty equipment can result in inaccurate data or safety problems and should be corrected as soon as possible. For these reasons, it is important that the data collection personnel realize the need to report problems.

- **Synchronize clocks** - All the stopwatches, computers, and vehicle clocks should be synchronized to within several seconds of one another for consistent times. Variations in start times can cause overlap or nonuniform coverage of the desired time periods. This is especially important when multiple test vehicles are collecting data on one study route to ensure the desired headway between vehicles is provided. It is important to note that computer clocks usually require a military format or an "a.m." or "p.m." designation. If no designation is provided, the default is "a.m." This can lead to the recorded times being 12 hours off, which may affect the recorded date as well.

- **Fleet vehicles** - The test vehicle technique may require the use of a special data collection vehicle instrumented with DMI or GPS equipment. It is generally advisable that fleet vehicles be used for these purposes. If personal vehicles are used, vehicle insurance should be evaluated to ensure that it includes liability requirements. Personal vehicle use may cause some problems with mileage reimbursement. Proper logging of mileage and some quality control or auditing process is required to prevent inaccurate or abuse of mileage charges. The problem of personal vehicle reliability can also be a problem (i.e., staff inability to conduct runs because their car would not start or mechanical breakdown during the run).

- **Periodic review of driving styles** - A review of test vehicle drivers' driving style is suggested before the beginning of each new study. There is a potential for wide variability among different persons' driving styles. Reviewing techniques will result in more consistent and accurate data collection results.

- **Quality control of data entry** - Most procedures require adequate quality control. The data entry from pen and paper or audio tape to electronic format requires staff to enter information into an ASCII text, spreadsheet, or database file. A supervisor should check the field sheets or audio compared to the electronic format on a sampling basis. The supervisor may review either a few entries per page or an entire page on a random basis. If problems arise, further checks are warranted and should be pursued.

- **Consistent electronic file naming** - Most data collection efforts will result in many electronic computer files. Naming of electronic files for different studies over several years becomes problematic without a consistent file naming scheme. Route names, direction, time, and date are some variables that can be used to create a file name. It may be useful to have drivers keep a log book of the travel time run including file name, start time, and any other relevant notes for the run. This may aid in sorting out and managing the raw data files.

- **Automation and quality control** - Automation of reduction and analysis procedures for individual travel time runs can reduce review time and potentially improve data quality. Spreadsheet and database programs can be used to provide average speeds for links and speed profiles. The speed profile for each travel time run should be reviewed before any aggregation of travel time runs is performed since this aggregation will mask errors. These errors (e.g., incorrect speeds along the corridor) may be discovered by reviewing the speed profiles. Quality control with regard to the formulas entered into the spreadsheet or database should also be performed. If automation is utilized, errors in spreadsheet or database calculations only need to be checked once. If automation is not used, the analysis formulas should also be sampled and checked with manual calculations.

- **Backup data** - The loss of computer data is always a concern. The study team should be prepared for lightning, computer viruses, equipment malfunction, or power surges. Saving all field data collection sheets as well as making printouts or backups of all electronic files will reduce the risk of losing the travel time data that has been collected.

Considerations Prior to Data Collection

Many planning elements should be considered prior to the data collection effort. These include the following:

- Preparation of a preliminary work schedule considering holidays, vacations, and other significant dates;

- Determination of the number of student, technician, and professional personnel that will be required to conduct the study;

- Scheduling and completing any service that will be required on the vehicles prior to the data collection effort (e.g., oil changes); and

- Training of drivers in driving styles and data collection methods. This includes an explanation of the appropriate driving style, special instructions for equipment operation, and explanation of relevant data collection forms.

Weekly Considerations

The following elements should be addressed on a weekly basis during the data collection effort:

- Cleaning the exterior and interior of vehicles;

- Checking vehicle tires including tread, sidewalls, and air pressure; and

- Updating a data collection progress report (see Table 2-8). A weekly progress report aids in ensuring that the data collection effort remains on schedule. If some travel time runs must be rescheduled due to an incident or suspect data, the weekly progress report helps in rescheduling these travel time runs. A progress report is especially valuable for large data collection efforts.

Daily Considerations

The following elements should be addressed on a daily basis during the data collection effort:

- Check the computer hard drive(s) for adequate data storage space;
- Check the battery life of the computer power source. If a power converter or cigarette lighter is being used from the vehicle, the connections should be investigated to ensure they are secure to avoid a power loss;
- Download data to the desktop storage computer for GPS and DMI test vehicle methods. For manual methods, the data may be reduced at a later date;
- Document any relevant information of importance about a particular travel time run. Depending upon the study design, this may include elements such as incidents, construction, and weather conditions;
- Fill the vehicle with gasoline if the tank has less fuel than required for a full data collection period after the daily data collection activities are completed;
- Fully document any problems with the data collection (e.g., incidents, accidents, vehicle difficulty, running late) for future reference; and
- Determine and address any problems that may have resulted during previous data collection efforts. Identify how to correct and prevent the problem in the future.

3.1 Manual Method

With the manual method, a trained driver uses one of the driving styles described at the beginning of this chapter while a passenger uses pen and paper, an audio tape recorder, a portable computer to record cumulative travel times along the study route. The test vehicle runs may be performed at prescribed start times or test vehicle headways. The focus of this section will be on collecting travel time data using pen and paper, including discussing equipment and personnel requirements, necessary procedures, and associated costs. Audio tape recorders and portable computers have been introduced to improve the quality and efficiency of the pen and paper technique. Although the discussion throughout this section will be based using pen and paper, these semi-automated improvements will also be discussed.

Travel time data are generally collected at checkpoints with 0.4 to 0.8 km (0.25 to 0.5 mi) spacing, depending upon the type of facility and the amount of additional data collected (e.g., queues, stops, construction, incidents). Driving in congested conditions increases the driver's workload, thus reducing the amount and/or frequency of data collection observations or checkpoints. A driver and observer collection team can be used to safely record all the required study information.

IMPORTANT ☞ Travel time data are generally collected at checkpoints with 0.4 to 0.8 km (0.25 to 0.5 mi) spacing, depending upon the type of facility and the amount of additional data collected (e.g., queues, stops, construction, incidents).

Pen and Paper Technique

The pen and paper technique requires a driver and a recorder, one or two stopwatches, data collection forms, and a test vehicle. The test vehicle is driven along the study route throughout the time period of interest, using set headways (typically 30 minutes) if desired. The recorder starts the first stopwatch as the driver passes the first checkpoint, recording the cumulative elapsed time at subsequent checkpoints on the field sheet. A second stopwatch may be used to record the amount of delay time incurred by the test vehicle when slowed or stopped (0 to 8 km/h, or 0 to 5 mph), also noting the cause of the delay. This procedure is followed through the entire course until the time at the final checkpoint is recorded. Several runs are usually made on the same route, requiring the test vehicle to return to the starting point. Data is typically collected on the study route in the reverse direction with little or no additional cost. The stop watches are reset, a new field data collection sheet is prepared, and the above procedure is repeated until the end of the study time period.

Audio Tape Recorder Variation

The audio tape recorder variation follows the same procedure outlined above for the pen and paper technique. However, a voice-activated tape recorder can be utilized to record the times instead of writing the times on paper. This method reduces or eliminates recording errors associated with the pen and paper technique. Transcription errors from documenting time intervals in the field are eliminated, but errors due to transcribing the audio tapes are possible. Speaking clearly into the tape recorder and having the individual who made the tape in the field transcribe the data aids in reducing transcription error with the audio tape variation.

Portable Computer Variation

A portable computer variation of the manual method has also been adopted to reduce errors and staff requirements. The portable computer variation utilizes the internal clock on the computer combined with some specialized software to record the travel times. There are no distance collection capabilities. Available or easily developed software can record the portable computer's clock time. The same pen and paper procedure is utilized, but the stopwatches and pen and paper are replaced by the portable computer's internal clock and computer files. This results in a reduction in staff requirements for field data collection and data entry. Computer keys are used to record predetermined checkpoints as well as other incidents and accidents. A time stamp as well as a description is written to the computer file.

Once the field travel time information is collected, reduction of the computer time stamps is required. Most data reduction and analyses are conducted using computer spreadsheets or databases. Pen and paper and audio tape methods require staff to transcribe the written or recorded times to electronic format. The pen and paper method requires two employees to collect the field information and someone to enter the information into electronic format. Incrementally, it is likely that tape recorders can aid the travel time data collection effort for a minimal additional equipment cost while reducing staff requirements. Transcription of audio tapes is still required and some degree of potential transcription errors still exist. In addition, there is the incremental cost effectiveness of using a portable computer over both the pen and paper and audio tape recorder methods due to the reduction of errors in collection and summarization of the travel time information. Using the portable computer accurately records the time to a data file, which eliminates any transposition and transcription errors and provides a consistent electronic file format that can aid in automation.

Having pointed out the advantages and disadvantages of the audio tape and portable computer variation, the discussion below will be based on the traditional pen and paper method. Equipment and staff requirements and associated costs will be based on this pen and paper technique. With all the manual methods, an element of human error exists in that the observer could inaccurately mark the predetermined checkpoints. Driver knowledge of each checkpoint location is essential. If the observer records the time at an improper location, either before or after the correct checkpoint, a faster or slower calculated speed will result. It is difficult, if not impossible, to correct for this type of human error with the manual method. DMI or GPS instrumentation can correct or eliminate this type of human error. Although these techniques solve some of the problems of the manual method, there are other considerations that the practitioner should realize. These are described in Sections 3.2 and 3.3 of this chapter.

3.1.1 Advantages and Disadvantages

The manual method (pen and paper) has the following **advantages**:

- No special equipment needs;
- Low skill level (no special hardware training); and
- Minimal equipment costs.

The manual method (pen and paper) has the following **disadvantages**:

- High labor requirements (driver and observer);
- Low level of detail (average speeds for 0.4 to 0.8 km, or 0.25 to 0.5 mi). Average speed and delay are reasonable while queue length and speed profiles are difficult;
- Greater potential for human error (potential for marking wrong checkpoints or inaccurate times);
- Potential data entry errors (e.g., recording travel time errors in the field and transcription errors from field sheet to electronic format);
- Cost and time constraints prohibit large sample sizes; and
- Little automation potential and only estimates of emission, fuel consumption, and other performance measure limitations due to the averaged speeds over 0.4 to 0.8 km (0.25 to 0.5 mi).

3.1.2 Cost and Equipment Requirements

This section will detail hardware, software, and personnel needs that are necessary when considering the implementation of any of the manual methods for travel time data collection. The cost and equipment requirements for the manual test vehicle technique are minimal. However, the cost of data collection can vary largely depending upon the skill level of the data collection personnel.

A detailed description of the procedure is explained in Section 3.1.3. The equipment for the different manual test vehicle techniques vary. The typical equipment and personnel requirements for the manual method are as follows.

- **Clipboards and stopwatches** - Hard writing surfaces are helpful for observers to record information on the field data collection sheets. Stopwatches provide the second increment of time which are useful for travel time data collection. Stopwatches that have large numbers are also helpful.

- **Portable audio recorders -** A voice activation feature starts the audio tape recorder from a pause mode, reducing the amount of tape and time recorded as well as the time required to transcribe the recording.

- **Portable computer** - Necessary for recording computer time stamps for the portable computer variation.

- **Power supply** - External power required by the portable computer supplied through the cigarette lighter. Batteries can be used but can prove to be unreliable.

- **Data storage computer** - Generally located back at the office, this desktop computer is used to store and process the field travel time data.

- **Test vehicle** - Vehicle used by the driver and/or recorder to travel the predetermined route. No special equipment is required for the manual method. A fleet or personal vehicle can be utilized with the proper insurance and mileage reimbursement.

- **Collection software** - In addition to a portable computer, the portable computer variation requires specialized software, either commercially available or developed, that utilizes the internal computer clock to record a time stamp.

- **Test vehicle driver -** Personnel are required to drive a test vehicle on the study route and perform the required tasks associated with travel time data collection.

- **Observer/Recorder** - Depending on the selected test vehicle method and the desired data collection, the observer records the elapsed time at the beginning checkpoint and all subsequent checkpoints as well as delay and queue information.

- **Data entry/reduction personnel** - Staff required to transcribe the travel time and distances to link speeds and perform any other required analysis. Computer programs, macros, and automation can reduce or eliminate this step of the process.

- **Supervision and management** - This includes a data collection manager who monitors the overall data collection, reduction, and analysis. This cost varies depending on the size and scope of the project, automation of data collection, reduction and analysis needs, as well as other study needs.

Table 3-5 provides cost information for the manual test vehicle technique. It should be noted that a good deal of quality control is required to ensure that all runs have been completed and that errors in recording, transcribing, or reducing the data are detected and corrected. In many cases, this may require runs to be recollected. Untrained and inexperienced data collection personnel can dramatically increase the cost of travel time data collection.

Table 3-5. Estimated Costs for the Manual Test Vehicle Technique

Equipment/Personnel	Unit Cost (1998 dollars)
Hardware	
Clipboards, Stop Watches	$20 to $50 per test vehicle
Optional: Portable tape recorders (voice activated)	$30 to $100 each
Optional: Portable Computer (Laptop/Palmtop)	$1,500 to $3,000/$500 to $700
Vehicle Operating Cost	$0.28 to $0.32 per mile
Software	
Optional: Collection Software (Commercial or Developed)	Varies
Personnel	
Test Vehicle Driver	$6 to $10 per hour
Observer/Recorder	$6 to $10 per hour
Data Entry/Reduction Personnel	$6 to $10 per hour
Supervision and Management	Varies

Consider the following cost estimates that present the expected differences in person-hours and capital costs for the various manual method variations. Assume that one would like to perform data collection during a peak period of 4 hours using the manual method. Assuming that one owns a data storage computer and the necessary spreadsheet software for analysis, the pen and paper manual technique costs are as follows (note that this results in 9 person-hours per 4 hours of data collection, plus vehicle operating expenses that will vary):

- 1 stop watch, clip board, data sheets, and pens/pencils ($25 total);

- 1 driver for 4 hours at 10 dollars per hour ($40 total);
- 1 observer for 4 hours at 10 dollars per hour ($40 total); and
- 1 hour of data reduction at 10 dollars per hour ($10 total).

With the same assumptions as above, the optional audio tape recorder variation costs are as follows (note that this results in 6 person-hours per 4 hours of data collection plus vehicle operating expenses):

- 1 stop watch, clip board, data sheets, and pens/pencils ($25 total);
- 1 voice activated portable tape computer ($100);
- 1 driver for 4 hours at 10 dollars per hour ($40 total); and
- 2 hours of data reduction at 10 dollars per hour ($20 total).

Finally, with the same assumptions as above, the portable computer variation costs are listed below (note that this results in 5 person-hours per 4 hours of data collection plus vehicle operating expenses).

- 1 laptop computer ($2,000);
- Software for data collection ($150);
- 1 driver for 4 hours at 10 dollars per hour ($40 total); and
- 1 hour of data reduction at 10 dollars per hour ($10 total).

3.1.3 Data Collection Instructions

The data collection instructions for using the manual test vehicle technique are explained in this section. The following steps should be performed before data collection is started (see Chapter 2 and earlier sections of this chapter):

1. Define the routes to be studied;
2. Designate the checkpoints and locations where link times and speeds are desired;
3. Define the time period during which data will be collected;
4. Determine the number of travel time runs that are necessary;
5. Develop a travel time data collection schedule; and
6. Training of test vehicle drivers along with one to two hours performing sample runs.

Training should include three aspects: 1) how to drive in the traffic stream (i.e., driving style); 2) how to fill in the data collection forms for the travel time run; and 3) how to check the equipment prior to the travel time run to ensure that it is ready for operation.

Once the necessary planning and preparation have been completed, the following steps should be performed to collect the data:

1. **Assemble equipment**. The following checklist can help ensure that all the necessary equipment is available and functioning properly:

    - test vehicle;
    - data collection forms;
    - map of the study route;
    - procedures on when to abort runs;
    - pens, pencils, and clipboard; and
    - stopwatches.

2. **Fill out field data collection form.** The recorder must fill out the run information pertaining to route, direction, date, scheduled start time, actual start time, weather, lightning, and pavement conditions. The driver should look over the checkpoints to become familiar with the name and order of the checkpoints.

3. **Begin to drive the travel time route**. The driver can then begin to drive the travel time route using the prescribed driving style.

4. **Mark beginning point of travel time run.** The driver will need to start the run at a consistent location while the recorder starts the stopwatch and marks the beginning of the travel time run.

5. **Mark all checkpoints or links and incidents.** The recorder should record the cumulative elapsed time at all predefined checkpoints. Incidents or queuing information should also be recorded by starting the second stopwatch. Reasons for the delay should also be recorded (e.g., queuing due to construction).

6. **Stop, record time, and reset stopwatches at the end of the run.** At the last checkpoint or ending point, the stopwatch should be stopped, the elapsed time recorded, and any notes about the run recorded before resetting the stopwatch to prepare for another run.

7. **Perform all subsequent travel time runs.** Typically, multiple travel time runs are conducted. It is advisable to collect data in both directions. Non-peak direction information can provide information about off-peak travel at little or no additional cost.

After personnel are properly trained and the drivers are proficient in preparing equipment for data collection, the actual data collection effort is quite simple. Upon completion of the travel time run, the data must be reduced to a common format for analysis. This can include transcribing times from field sheets or audio tape. If portable computers are being used, the data need to be downloaded to a desktop storage computer. Data management and storage are critical. Consistent file naming aids with associating a data file with its respective facility and run. Data management is essential to ensure that once data are collected the files are not overwritten as new data files are added. This is especially true for large data collection efforts. Care must be taken to ensure the data are collected, stored, and managed carefully to optimize data storage and reduce accuracy errors. All field data sheets should be kept even after the data has been entered into electronic format. Original sheets can be used for quality control and provide insight or reasons for unexpected travel times or conditions.

Examples of data collection forms are shown in Figures 3-1, 3-2, and 3-3. Figure 3-1 shows "short-hand" techniques that can be used to mark queues and incidents. Figure 3-2 shows an example data collection form for the average vehicle method from ITE's *Manual of Transportation Engineering Studies*. Figure 3-3 illustrates a sample data collection form from Chapter 11 of TRB's *1994 Highway Capacity Manual*.

Additional Data Collection Considerations

Past experience with the manual test vehicle technique has resulted in a wealth of knowledge. The following lists were developed based upon the past experience of others. Section 3.0.3 provides a list of general considerations for all test vehicle techniques. The following sections describe helpful tips for the manual (pen and paper) method and variations of the method (i.e., audio tape recorder, portable computer).

Pen and Paper

> **Large Display on Stopwatches** - A large stopwatch display will reduce the errors in reading the stopwatch (e.g., "8"s being confused with a "3" or "5"). These errors are nearly impossible to find unless the errors are very drastic (i.e., negative speeds result when an "8" is written as a "3").

Audio Tape Recorder

> **Voice-activated audio tape recorders** - A valuable feature on some audio tape recorders is voice activation. This feature starts the recording when sound is detected. Voice activation will reduce the tape and battery use during the travel run. It will also reduce the time required to reduce the travel time data since only a small portion of the tape has recorded data. Without this feature, data reduction personnel are required to listen to the entire tape and they must attempt to fast forward and stop where checkpoints

IH 10 KATY FREEWAY - MAINLANES - WB DATE: 5/28/96

SECTION LIMITS LANDMARK	CUM. MILE	INT MILE	CUM. TIME	ADVERSE CONDITIONS: WEATHER, LIGHT, PAVEMENT, INCIDENT, CONSTRUCTION
Hogan Street Overpass Overpass past SPRR Overpass	---	---	---	
Taylor Overpass	1.00	1.00	2:24	Queue Starts
Shepherd Overpass, Texaco on right	2.70	1.70	7:30	
SPRR Stair-stepped overpass	3.60	0.90	10:12	
Washington Overpass, Dennys on right	3.90	0.30	10:55	Construction Starts
East Terminus At structure	4.82	0.92	13:41	
West Loop (610) Overpass	5.40	0.58	15:25	
AVL Flyover At structural beam	5.85	0.45	16:46	
Silber Shell on left	6.35	0.50	17:58	Construction Ends - Queue Ends
Antoine Underpass	6.80	0.45	18:45	
Wirt Exxon on left	7.37	0.57	19:32	
Bingle Underpass	8.19	0.82	20:26	
Blalock Fiesta on right	9.55	1.36	22:03	Stall Right Shoulder-Queue Starts
Bunker Hill Texaco on left	10.18	0.63	22:50	
Gessner AVL Exit At structure	10.63	0.45	23:26	Light Rain
Gessner Memorial City Mall on left	10.93	0.30	23:50	
West Belt (Beltway 8) Overpass	12.08	1.15	25:06	
Wilcrest Underpass	12.83	0.75	25:56	

ADVERSE CONDITIONS

WEATHER	LIGHT	PAVEMENT	CONSTRUCTION	INCIDENTS
Overcast	Dark or Twilight	Wet	Minor (off shoulder)	Minor (off road)
Light Rain or Drizzle	Sun Glare	Ice or Snow	Major (lane blockage)	Major (lane blockage)
Heavy Rain	Fog			

DIRECTIONS

AT END OF WB RUN	AT END OF EB RUN
• Exit at Fry Road • Take overpass to make U turn • Stop and enter data at shell gas station • Turn onto frontage road and take ramp to IH 10 EB	• Exit IH 10 at Smith Street • Turn left into Bank 1 drive through teller area • Enter data • Turn left onto Louisiana and take ramp to IH 10 W

Figure 3-1. Example 1 of Manual Test Vehicle Data Collection Form

TRAVEL-TIME AND DELAY STUDY
AVERAGE VEHICLE METHOD
FIELD SHEET

DATE __________ WEATHER ________________ TRIP NO. ________________

ROUTE ________________ DIRECTION ________________________________

TRIP STARTED AT ____________ AT ________________________________
(LOCATION) (MILEAGE)

TRIP ENDED AT _____________ AT ________________________________
(LOCATION) (MILEAGE)

CONTROL POINTS			STOPS OR SLOWS		
LOCATION	TIME		LOCATION	Delay (seconds)	

TRIP LENGTH	TRIP TIME	TRAVEL SPEED
RUNNING TIME	STOPPED TIME	RUNNING SPEED

SYMBOLS OF DELAY CAUSE: S-TRAFFIC SIGNALS SS-STOP SIGN LT-LEFT TURNS

PK-PARKED CARS DP-DOUBLE PARKING T-GENERAL

PED-PEDESTRIANS BP-BUS PASSENGERS LOADING OR UNLOADING

COMMENTS ________________________________ RECORDER ________________

Source: adapted from reference (1).

Figure 3-2. Example 2 of Manual Test Vehicle Data Collection Form

TRAVEL TIME FIELD WORKSHEET

Arterial____________________________________ Date________________

Driver_____________________ Recorder________________ Direction______________

SIGNAL LOCATION	DISTANCE (MI)	Run No. Time CUMULATIVE TT (SEC)		STOP TIME (SEC)	Run No. Time CUMULATIVE TT (SEC)		STOP TIME (SEC)	Run No. Time CUMULATIVE TT (SEC)		STOP TIME (SEC)

S – Signal (lower box)
LT – Left Turn (upper box)
P – Pedestrian (upper box)
PK – Parking (upper box)
4W – 4-Way Stop (upper box)

Source: *1994 Highway Capacity Manual*, Chapter 11.

Figure 3-3. Example 3 of Manual Test Vehicle Data Collection Form

- **Data transcription** - Recorders should transcribe the runs that they performed. Differences in annunciation and dialects can cause errors. In addition, observer's notes may be helpful for determining any anomalies in the travel time run. Audio tapes can be reused after sufficient quality control is conducted.

- **Safety** - A driver and a recorder should be used to collect travel time data using the manual test vehicle technique. Occasionally, drivers are required to wait for a headway start time or must enter data. The location of this stopping point should be in a highly visible and populated area. In urban areas, an undesirable or dangerous area may cause a threat to data collection personnel. Drivers should always keep vehicle doors locked in such situations.

Portable Computer

- **General considerations** - As technology increases, there are greater chances of technical problems. There are some problems that can occur using the portable computer variation, but the benefits of requiring only one driver (as opposed to a driver and a recorder) is cost-effective. The fact that data are in electronic format also makes the portable computer version cost-effective. Portable computers are fairly common and the low cost of software and shareware make this method the most desirable manual method. In addition, portable computers do not require additional hardware that must be attached to fleet or personal vehicles.

- **Power Supply** - Portable computers require a generous amount of power. Energy consumption varies with processing and accessing the hard disk. A cigarette adaptor or power inverter solves problems with batteries running out during a travel time run.

- **Screen Savers** - Some computers have a sleep mode and/or screen savers. These programs are designed to reduce power consumption or save the integrity of the screen. However, these programs can interfere with the travel time software operation causing the program to lock, crash, or provide inaccurate results. These features should be disabled for field data collection.

- **Remove Equipment** - Portable computers and other expensive equipment should never be left in a vehicle. Thieves may break into the vehicle, steal the equipment, and damage the vehicle.

3.1.4 Data Reduction and Quality Control

Several steps are necessary in data reduction for the manual test vehicle technique:

1. **Review field data sheets and/or computer files.** Incidents, accidents, and anomalies should be recorded. These comments can provide valuable insight to field conditions at the time of the travel run.

2. **Transcribe travel time from field sheets or audio tape.** Travel times and delay information should be transcribed to a consistent electronic format. A systematic review of entered data will provide a quality control check as well. Spot checking one entry per travel time run is one method of checking the consistency from field sheet to electronic format.

3. **Calculate and plot link speeds.** Perform relative calculations of speed, percent time, and other desired MOEs. The data can then be plotted for easy visual comparison.

4. **Review tabulated results and speed profile for each run for reasonableness.** Tabulated results and speed profiles provide a valuable tool for the supervisor to review each run. Questions such as the following can be quickly assessed: Do the average speeds reflect the expected or historical trends? Are bottlenecks reflected on the speed profile?

Analysis for all variations of the manual test vehicle techniques listed above are similar. Since the travel times are recorded at predetermined checkpoints, known distances can be obtained from field measurements or scaled from maps. By knowing the distance and travel time(s) between each checkpoint, a space-mean speed can be calculated. The limited amount of data from checkpoints, typically spaced at 0.4 to 0.8 km (0.25 to 0.5 mi), can be analyzed manually with a spreadsheet, database, or statistical analysis package with relative ease. The size (i.e., number of corridors and number of runs) and frequency (i.e., number of times a year and number of years) of the study may determine the desired level of automation.

EXPERT TIP ☺

The level of automation for data reduction should be determined by the size and frequency of travel time studies. Automation can initially be time-consuming but it often pays off over several years.

Desired analyses can be performed after the data reduction procedure has been completed. Aggregation of travel time runs should only be performed after each individual run is scrutinized for accuracy. Aggregation masks errors and can skew results. This makes it extremely difficult to determine where the error occurred. Therefore, quality control is essential. Further analyses and/or aggregation for different time periods, functional classes, and/or area types can also be conducted.

CAUTION !! Data quality control is very important at all stages of collection, reduction, and analysis to ensure that the data and analysis results are accurate and reliable.

Quality control checks should be in place to ensure that the quality and quantity of data is being reported as accurately as possible. Field data collection sheets should be reviewed for completeness. The route information in the header and the time information should be logical to ensure field recording errors are not continued further into the process. Logical checks include: time is increasing, transposition errors, and comparison against other runs or historical data. The data entry is another source of error with interpretation, transposition, or simple typing errors. These can be checked by comparing a sampling of the entered data to the raw data. At any point, if errors are detected, a more careful screening of the data may be required. If automation is employed, errors in spreadsheet or database calculations only need to be checked once. If automation is not employed, the analysis formulas should also be sampled and checked with manual calculations.

Amount and Type of Data

The amount of data collected from the test vehicle technique varies. Only a limited number of control checkpoints can be safely, accurately, and effectively gathered. As previously mentioned, control checkpoints spaced approximately 0.4 to 0.8 km (0.25 to 0.5 mi) are typical for this technique. Congestion cause and effect data, as well as delay data, can usually be collected with moderate results. Observers can usually record the cause of delay such as incidents, accidents, or stalls. Delay information is obtained by recording the time from the stop watch and the odometer reading from the vehicle. The delay information is somewhat difficult to collect because of the "stop-and-go" nature of congested traffic conditions. It is sometimes difficult to define the start and end of a rolling queue. Experience, some predefined condition such as below a specified speed, being stopped at a traffic signal, or other criteria will aid field personnel in consistently collecting the required data.

3.1.5 Previous Experience

Nearly all agencies that have conducted travel time studies in the past 20 years have used the manual test vehicle technique. This section describes specific experience gained by the Texas Transportation Institute from extensive travel time studies over the past 10 to 15 years in Houston, Texas.

Texas Transportation Institute, Houston, Texas

The Texas Transportation Institute (TTI) has been extensively involved in the collection of travel times for a host of ongoing studies. One study is *An Evaluation of High-Occupancy Vehicle Lanes in Texas* (9). The data collection, reduction, and analysis of travel times for this ongoing study have covered most of the methods reported in this chapter. The pen and paper method was originally used due to its simplicity and flexibility. Travel times were collected in the field by using a stopwatch and pen and paper to record the travel times. Once the data was collected, the data was entered into a spreadsheet and the average speeds were calculated. Moderate checks for data entry were conducted to ensure that transposition errors were caught. Further processing of the data was conducted using a software package for statistical analysis. Comparisons of the data were made from other quarters and other years.

Five years ago, several methods of travel time data collection were tested. The audio recorder method provided a reduction in staff required to collect the travel time data. The travel time information and procedures were the same except for the method of recording the clock times. As with all methods there were many lessons learned.

- **The person who records the travel time should enter the information into electronic format.** On several occasions the dialects and annunciations caused errors for data entry.

- **Voice-activated tape recorders work best.** Standard tape recorders provided a lot of tape to fast forward through. Further, many checkpoints were missed because the pause button was not turned off or tape was not rolling when the times were recorded to the audio tape.

- **Observers should announce the checkpoint and the time.** Failure to do so results in guess work and interpretation of what checkpoint was being recorded and sometimes the delay information was interpreted as checkpoint times.

- **Prompt reduction and analysis of data provided the best results.** Supervisors could question drivers on travel conditions if unexpected results were encountered.

- **Extra batteries and tapes should be provided.** Battery life is unpredictable and for a small cost the rescheduling of data collection is prevented. On most audio tape recorders there are two tape speeds. If the faster tape speed is selected, the recorder could run out of tape before all the runs are completed. Once the data from one data collection effort has been entered, the tapes can be used again.

3.2 Distance Measuring Instrument

The electronic distance measuring instrument (DMI) is used for a variety of applications, such as route numbering, emergency 911 addressing, acreage and volume calculations, as well as general linear distance measuring for pavement markings. These instruments are very accurate once calibrated (plus or minus one foot per mile, or 0.19 meter per kilometer).

Travel time data collection with manual DMIs was conducted in the early 1970s. Original DMI units used an adding machine tape or printer to record the distance and speed from the unit. A circular graph known as a tachograph was used to continually record distance and speed. These manual DMI units used a magnetic wheel sensor to measure revolutions. Calibration was provided by knowing the number of revolutions over a fixed distance. When properly calibrated, these devices provided accurate results. However, there were some problems with this technology. Wheel sensors would fall off or not read properly and sometimes unbalance the wheel. Data media was paper format, either circular graphs or adding machine tape, which were difficult to read and required large amounts of data entry. The advent of the electronic DMI solved these problems.

Figure 3-4 illustrates the equipment typically used in electronic DMI data collection. The electronic DMI calculates distance and speed using pulses from a sensor attached to the vehicle's transmission. These pulses are sent from the transmission to the sensor based on the vehicle's speed. The DMI converts the pulses to units of measure and calculates a speed from an internal clock. The DMI unit is able to send the data to a portable computer for storage. Specialized software can be used to record the electronic information, eliminating the data entry and errors associated with the older models. Notes can also be added to the end of the file to describe incidents or other relevant information about the travel time run. A consistent data format allows for automation of reduction and analysis of travel time information.

Commercial and proprietary software can be used to interact with the DMI or read the pulses directly from the transmission sensor. The DMI is essentially a specialized piece of hardware/software that interprets the pulses from the transmission sensor and converts them into a distance. Most software packages provide a data collection module (field data collection) as well as reduction/analysis software. These software packages allow collection for multiple runs and data reduction including tabular summaries and speed profiles. Some DMI manufacturers have proprietary collection and analysis software, while others provide example computer code to read the data from the DMI. This allows users to develop and customize the data collection and analysis software. File format, sample rate, and report format are among the most relevant issues for researchers and practitioners to customize in the data collection and analysis software. Appendix A contains additional information about computer software available for test vehicle techniques.

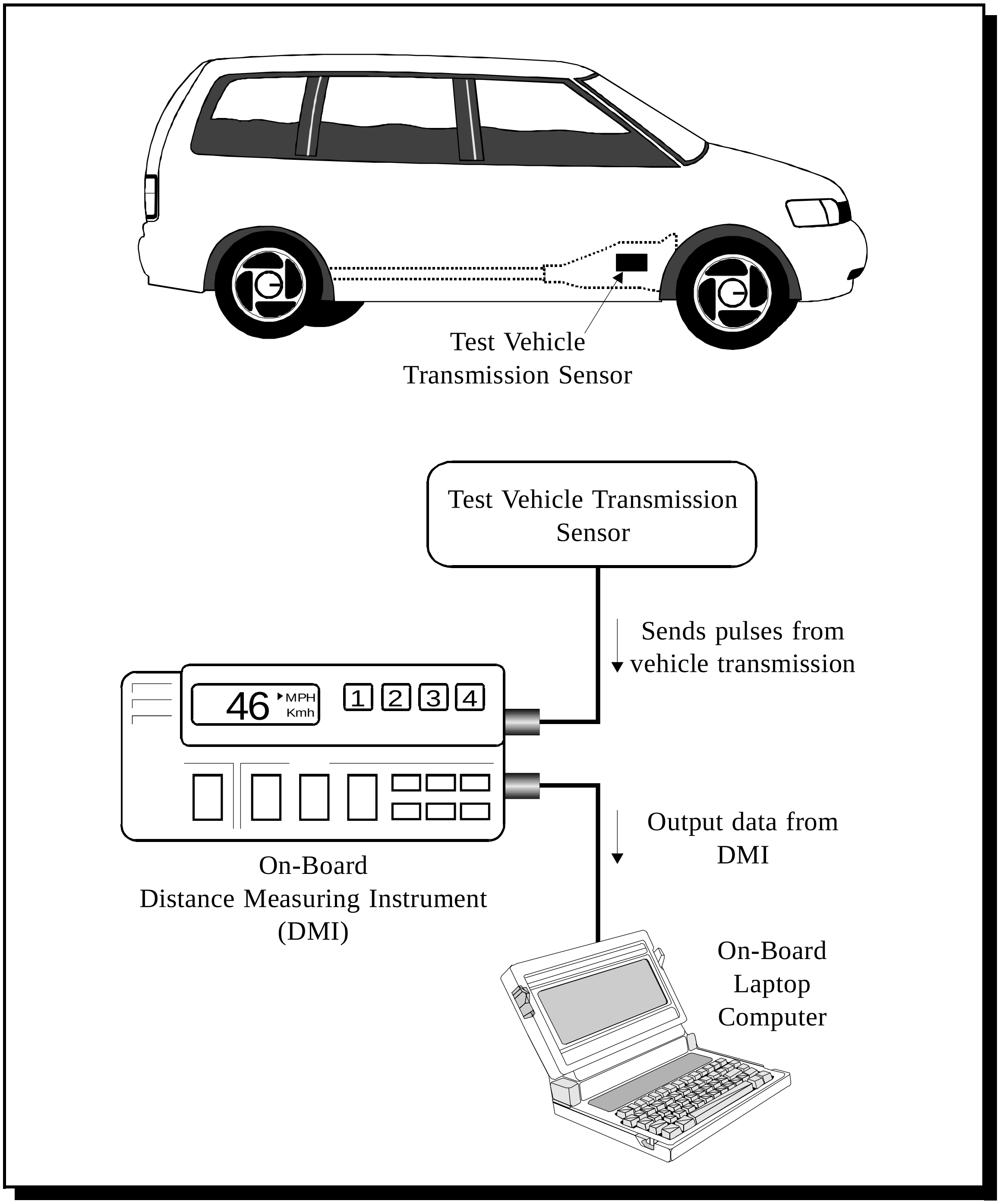


Figure 3-4. Typical Equipment Setup for DMI Test Vehicle Data Collection

3.2.1 Advantages and Disadvantages

Test vehicle data collection with an electronic DMI has the following **advantages** (as compared to the other test vehicle methods):

- Reduction in staff requirements compared to the manual method. There is no passenger recording information. No data to enter or errors associated with data entry (e.g., transposition, format);
- Reduction in human error including missed checkpoints or incorrectly recording information. However, the starting point or first checkpoint must be accurately marked;
- Offers some redundancy of checkpoint locations as long as the first checkpoint is marked properly;
- Commercially available software provides a variety of collection and analysis features;
- Field notes, incidents, and anomalies electronically recordable at the location the incident occurred available in most software packages;
- Increased amount and variety of data available for applications including determining queue lengths, stopped delay, average speed, link speeds, detailed speed profiles, input to models for planning, emissions, or fuel consumption, and performance evaluation computation;
- Relatively cost-effective and accurate;
- Provides data in a consistent format to aid in the automation of data reduction and analysis automation; and
- Proven technology.

Test vehicle data collection with an electronic DMI has the following **disadvantages**:

- Storage requirements for the vast amount of data collected;
- Must be calibrated to obtain accurate results;
- Requires accurate marking of first checkpoint;

- Not readily adaptable to a geographic information system (GIS) (raw data are not geocoded); and

- Some assembly is required, including the sensor wiring. It cannot be moved from one vehicle to another.

3.2.2 Cost and Equipment Requirements

This section details the hardware, software, and personnel needs for travel time data collection with an electronic DMI:

- **Test vehicle driver** - Personnel are required to drive a test vehicle on the study route and perform the minimal required tasks associated with travel time collection.

- **Data reduction personnel** - Staff required to transform the travel time and distances to link speeds and perform any other analyses required. Computer programs, macros, and automation can reduce or eliminate this step of the process.

- **Supervision and management -** This includes management personnel who monitor the overall data collection, data reduction, and analysis of the system operation. This cost varies depending on the size and scope of the project, automation of data collection, reduction and analysis needs, as well as other study needs.

- **Transmission sensor** - Reads pulses from the test vehicle transmission.

- **Distance measuring instrument (DMI)** - Hardware unit that interprets the information from the transmission sensor and converts it to a distance and speed.

- **Portable computer** - Necessary for recording travel time data in the test vehicle.

- **Power supply** - External power required by the portable computer supplied through the cigarette lighter. Batteries can be used but usually prove to be unreliable.

- **Data storage computer** - Generally located back at the office, this computer is used to store and process the field travel time data.

- **Test vehicle** - Fleet or agency vehicle used by the driver to travel the survey route. A transmission sensor must be attached to the vehicle for the DMI method.

- **Collection/Reduction/Analysis software** - Software that is purchased or developed that either reads the information from the transmission sensor or DMI unit with the ability to generate useful statistics and speed profiles. Appendix A provides more detail on system requirements and vendor contact information for this software.

Figure 3-4 illustrates the equipment requirements and setup. The DMI is connected to the transmission sensor via a modular phone-type connector. The DMI data is output to the on-board portable computer. The portable computer stores the data at given time intervals as the vehicle travels the roadway. When the travel time run is completed, the portable computer information is downloaded to a data storage computer.

Table 3-6 displays estimated costs for software, hardware, and personnel requirements. Moderately skilled personnel are required for electronic DMI data collection. A general knowledge of computer and software operation is necessary. Generally, this can be provided with a half-day of training. Data reduction personnel skill level depends on the complications that may occur. Most analysis software requires clean raw data with no field errors (e.g., incorrectly marked start point, incorrect units, incorrect calibration number). Most software has limited tolerance for such mistakes. Some errors can be corrected if caught early and the proper data is retrieved from the DMI unit. All DMI data collection requires a transmission sensor. Some software packages interface directly with the transmission sensor, while others require hardware (e.g., DMI or electronic count board) to interface with the transmission sensor. Analysis software is usually bundled with the collection software. Varying degrees of further analysis can be performed with any proprietary spreadsheet or database software depending on the level the collection/analysis software developer provides.

The data storage computer is also shown in Table 3-6 for completeness. However, this is generally not an added cost because an existing computer can be used for the data storage, provided there is ample space on the hard drive. In addition, it is likely that the portable computer may already be owned. Therefore, it would not incur a cost. Generally, the cigarette lighter on the vehicle or a battery pack is used as a power source.

Table 3-6. Estimated Costs for the Electronic DMI Test Vehicle Technique

Equipment/Personnel	Unit Cost (1998 dollars)
Hardware	
Transmission Sensor	$75 to $150
Electronic DMI Unit with RS-232 Connection	$450 to $650
Portable Computer	$1,500 to $3,000
Vehicle Operating Cost	$0.28 to $0.32 per mile
Software	
DMI Collection/Reduction/Analysis Software	$150 to $1,000
Proprietary Analysis Software (Spreadsheets, Database, GIS)	$200 to $3,000
Personnel	
Test Vehicle Driver	$6 to $10 per hour
Data Reduction Personnel	$6 to $10 per hour
Supervision and Management	Varies

A variety of hardware and software configurations are available. This will result in different costs and capabilities. For example, a transmission sensor, DMI unit, cable, and collection,/reduction software that requires a proprietary spreadsheet may cost about $1,170. The system chosen should be based on the current and potential need for the data and what each hardware and software system will provide. Other considerations include ease of use for collection and analysis and the types of analysis and level of detail that raw data can be provided.

3.2.3 Data Collection Instructions

The following steps should be performed before data collection starts (see Chapter 2):

1. Define routes to be studied;
2. Designate checkpoints or desired time/distance collection interval;
3. Define the time period during which data will be collected;
4. Determine the number of travel time runs that are necessary; and
5. Train test vehicle drivers with one to two hours of practice runs.

Training should include three aspects: 1) how to drive in the traffic stream (i.e., driving style); 2) how to operate the electronic DMI unit; and 3) how to check the equipment prior to the travel time run to ensure that it is ready for operation.

Once the necessary planning and preparation have been performed, the following steps should be performed to collect the data with an electronic DMI:

1. **Inspect equipment.** Ensure that all equipment is operating correctly:

    - All connections between the DMI, transmission sensor, portable computer, and power supply should be checked to ensure they have not become unattached.

    - Check DMI for proper calibration number and distance and speed data collection units (miles, mph or km, km/h). Different analysis software may require different units for reduction.

2. **Turn on equipment**. The operator then turns on the portable computer and the DMI unit. Depending upon the software being utilized, the operator will be prompted for necessary identifying information about the travel time run. After completion of these data inputs, the portable computer should begin to display information as the data are collected. The operator should ensure that the data appear to be collecting in the appropriate manner and line-by-line data are scrolling up the screen.

3. **Begin to drive the study route**. The driver can then begin to drive the study route and the DMI unit will collect the distance and speed of the test vehicle and send the information to the portable computer.

4. **Mark beginning point of travel time run.** The driver will need to start the run at a consistent location and mark (with a pre-determined keystroke) the beginning of the travel time run.

5. **Mark all checkpoints or links and incidents.** If the starting point is known, all subsequent checkpoints can be derived. It is advisable to mark all checkpoints (with a predetermined keystroke) in accordance with the software manufacturer's instructions to provide redundancy. Incidents or queuing should also be noted by the observer to provide annotation of events that may alter traffic operations.

6. **Perform all subsequent travel time runs.** Typically, multiple travel time runs are conducted in both directions to provide an average travel time based on an adequate sample size.

Upon completion of the travel time runs, the portable computer can be taken to the office to download the information onto a desktop computer for permanent storage.

Once personnel are trained and drivers are proficient in preparing the equipment, the actual data collection effort is quite simple. Data management and storage are critical. Consistent file naming aids in associating a data file with its respective facility, direction, time, and date. These data management considerations are especially true for large data collection efforts, and care must be taken to ensure the data are collected, stored, and managed carefully to optimize data storage and reduce errors.

CAUTION !! Adequate data management and consistent file-naming schemes are essential to ensure that once data is collected, the files are not overwritten as new data files are added.

Additional Data Collection Considerations

- **Calibration** - Calibration is very important in collecting accurate distance information with an electronic DMI. The calibration is vehicle dependent and varies by tire size, wear, and pressure. Not only is tire maintenance necessary for accurate DMI data collection, it is a safety and cost issue. Properly maintained tires last longer and are more fuel efficient. The calibration log sheet shown in Table 3-7 provides documentation of fluctuations in calibration and tire pressure.

IMPORTANT ☞ Vehicle and electronic DMI calibration should be conducted before every large data collection effort and periodically throughout data collection.

The calibration procedure involves putting the unit in calibration mode and driving a 305-m (1,000 ft) course. Calibration numbers can easily be changed, but if there are an equal number of DMI units and test vehicles, a helpful solution is to assign each vehicle a DMI unit. The tire pressure and calibration will still need to be checked periodically, but this will reduce changing and the potential errors of having the incorrect calibration number. The reader is encouraged to review Section 3.0.3 for additional data collection considerations for the test vehicle technique.

Table 3-7. Example of Weekly DMI Calibration Log

DMI Unit	Vehicle #	DMI Unit CAR #	Tire Pressure FL/FR/RL/RR	Calibration #	Driver's Name	Calibration Date
before#2	3582	2	30 / 31 / 33 / 29	819	Benz	5/15/95
correct#2	3582	2	31 / 33 / 33 / 32	822	Benz	5/15/95
			/ / /			
			/ / /			
			/ / /			
			/ / /			
			/ / /			
			/ / /			
			/ / /			
			/ / /			

3.2.4 Data Reduction and Quality Control

Several steps are necessary in the reduction of DMI travel time data:

1. **Review field data sheets and computer files.** Observers should record incidents, accidents, and anomalies. These comments can provide valuable insight into field conditions at the time of the travel time run.

2. **Check data file length and units**. Most analysis software requires the field output file to be in consistent units, typically distance is in feet or miles and speed is in mph. A quick and easy check is to ensure that the travel time run distance recorded is at least as long as the predefined route. Data files that are too long or too short typically mean the driver deviated from the prescribed route or an improper calibration number was used. Another consideration is that the file may have been misnamed.

3. **Run analysis software.** Most analysis software packages provide both a tabular format and a speed profile.

4. **Review tabulated results and speed profile for each run for reasonableness.** Both forms provide a valuable tool for the supervisor to review each run. Questions such as the following can be quickly assessed: Do the average speeds reflect the expected or historical values? Are bottlenecks reflected on the speed profile?

Desired analyses can be performed after the data reduction procedure has been completed. Aggregation of travel time runs should only be done after each individual run is scrutinized for accuracy. Aggregation masks errors and can skew results. This makes it extremely difficult to determine where the errors may have occurred. Therefore, quality control is essential. Analysis can be aggregated and averaged for different time periods, functional classes, and/or area types.

3.2.5 Previous Experience

California Department of Transportation

The California Department of Transportation (Caltrans) uses DMI software they developed to collect travel time information for congestion management and delay analysis purposes (10). The "tach run" methodology utilizes information collected by varying numbers of test vehicles traveling in the traffic stream to estimate recurring congestion delay. It should be noted that a tach run is simply the nomenclature used at Caltrans for a travel time run, and they are the same. With the exception of District 07, all of the urban Caltrans districts currently use this method to produce recurring congestion delay estimates. As this handbook went to press, Caltrans was considering the termination of this program.

Currently, test vehicles traverse the congested segments of freeway [i.e., areas where speeds less than 56 km/h (35 mph) are experienced for at least 15 minutes] during typical weekday peak periods, 6:00 to 9:00 a.m. and 3:00 to 6:00 p.m., Tuesdays through Thursdays. Several vehicles negotiate the segments at 15- to 20- minute headways. A minimum of four satisfactory observations are collected each year, one during the morning and afternoon peak periods for the spring and fall seasons. A satisfactory set of observations is defined as a complete run conducted under representative recurring congestion conditions. Therefore, if an accident is observed during the tach run, or the equipment malfunctions, the run is aborted.

As peak periods lengthen, however, it becomes increasingly likely that runs will have to be extended to fully capture recurring congestion delay on the California highway system. In addition, some concern has been expressed regarding recurring recreational congestion. For example, vehicles on Interstate 80 and Highway 50 in District 03 encounter increased delays on Friday and Sunday nights during the ski season.

After a successful tach run, the raw data is downloaded and input into a Caltrans computer program that computes speed, travel time, and delay. The delay is calculated as the difference between the time required to travel the specified distance at 56 km/h (35 mph) and the actual travel time (when speeds are less than 56 km/h (35 mph) for at least 15 minutes). The program automatically generates speed profiles and delay tables, from which congestion maps are produced.

Although the procedures for analyzing data and generating output are relatively simple for this methodology, the data collection process is extremely time consuming. It is estimated that over 100 hours are required per set of observations. A set of observations represents a tach run on a section about 8 to 16 center-line km (5 to 10 center-line miles) in length. Incidents and equipment failures often result in aborted runs. Data can be adjusted, however, for missing pulses. Due to the labor-intensive nature of the tach run methodology, the operating costs incurred are somewhat higher than those for other field study techniques. Additional costs include the purchase and maintenance of both the test vehicles and the on-board equipment. However, these are small compared to the costs involved in annual operations. Table 3-8 shows the expenditures in person-years for 1992-93 and the funds allocated for 1993-94 for the Highway Congestion Monitoring Program (HICOMP). The funds for each district represent the amount used/allocated for implementation of the tach run methodology, with the exception of District 07, which uses detectors.

Table 3-8. HICOMP Expenditures (Person-Years)

	Total Person-Years (1992-93)	Allocated Person-Years (1993-94)	Congested Directional Miles (1992)	Person-Years per Mile (1992)
District 01				
District 02				
District 03	0.8	0.68	41	0.0195
District 04	5.07	4.44	240	0.0211
District 05	0.29	0.12		
District 06	0.34	0.44	13	0.0262
District 07	2.27	2.50	521	0.0044
District 08	2.27	1.20	117	0.0194
District 09				
District 10		0.12		
District 11	0.83	1.10	104	0.0080
District 12	1.77	1.29	189	0.0094
Headquarters	0.87	2.45		
Other	0.28			
Total	**14.79**	**14.34**	**1225**	

Source: adapted from reference (10).

In 1992-93, the urban districts utilizing the tach run method accounted for 77 percent of the funds allocated by Caltrans for congestion monitoring. Only 57 percent of statewide recurring congestion delay was located in these districts. If and when peak periods are lengthened and/or extended to weekends, the proportion of funds spent by districts using tach runs to monitor congestion delay will likely increase. It is also interesting to note the range in expenditures per mile for these districts, from 0.0080 person-year/mile (0.0050 person-year/km) (District 11) to 0.0262 person-year/mile (0.1628 person-year/km) (District 06).

Although individual tach runs provide fairly accurate speed information, the accuracy of the methodology as a whole is somewhat uncertain. Not only must the tach vehicles be properly calibrated (known distance equals distance derived from tachometer data) at the beginning of each season, but additional calibrations may become necessary if vehicle tires are either rotated or replaced before the end of the season. As with any field study methodology, the number of observations included in the sample affects the reliability of the results (e.g., average speed and travel time).

Variability between districts and vehicle operators represents another factor to consider when evaluating the accuracy of this method. Additional observations and shorter headways are desirable for statistical purposes, but they are impractical due to the prohibitive costs of additional tach runs. Further study of the accuracy of the current methodology is recommended.

Unlike surrogate or traffic models, the tach run methodology does not produce output beyond what is required for estimating delay. It does, however, provide accurate spot speeds, space-hour statistics (e.g., mile-hours of congestion), and the opportunity to observe freeway sections under peak period conditions. The latter assists Caltrans in recognizing operational problems. The speed plots produced can also help to pinpoint bottleneck locations. If runs including observation of incidents are completed, travel time data could also be used for some non-recurring congestion applications.

The tach run methodology is not the most comprehensive field study technique. However, unlike the detector methodology, the initial start-up costs are minimal as only a few vehicles, tachometers, and portable computers are required. It is also extremely simple to implement and maintain. Unfortunately operating costs are high and the accuracy of the methodology is questionable. In particular, there is a lack of uniformity between vehicle operators and districts with regards to the following: when to abort a run, vehicle headways, the period of time to be studied, and the method of calculating delay. For more accurate delay estimates, a more complete picture is desirable (e.g., freeway conditions between tach vehicles) and different methods should be considered. Extending the peak periods and performing tach runs on weekends, although costly, would improve the current methodology.

Brigham Young University (BYU)

Thurgood developed a speed-based Freeway Congestion Index (FCI) to measure recurring congestion on freeways (11). A 9.7 km (6 mi) segment of I-15 in Salt Lake City was used to test the viability of the FCI. The FCI reflects both the extent (length) and duration of congestion on a given freeway segment, and can be used to compare different freeway segments of differing sizes or changes in congestion over time. The FCI is based on the distance that travel speed falls below 64 km/h (40 mph). This was based on the HCM LOS E/F (e.g., forced flow conditions).

A series of travel time runs were conducted using the Moving Vehicle Run Analysis Package (MVRAP) software (see Appendix A for more details) to collect detailed travel time and speed data. The instrumentation of the vehicle included the use of a DMI, an on-board computer, and the MVRAP software. The MVRAP software collected speed information from the DMI on a distance basis every 60 meters (200 feet). The "average car" travel time data collection method was employed. Test vehicles collected data along the test routes at 20- to 30-minute headways.

Speed profiles were printed and a horizontal line at 64 km/h (40 mph) was drawn and the distance below the threshold speed was measured. It was noted that the MVRAP software could not be modified to yield a distance traveled below any selected speed and thus required the manual calculation. The information is collected by the program and software modification calculates the FCI.

The study also found the speed or travel time runs taken from a single lane can be used accurately to represent the other lanes on the freeway facility. Although the level of congestion generally decreases somewhat going from the outside lane to the inside lane, regression equations have been developed that accurately provide an FCI for all lanes based on measurement of congestion in only one lane.

General Experiences

Several studies have been performed that summarize the experiences from many state departments of transportation (DOTs) and metropolitan planning organizations (MPOs) in utilizing DMIs for travel time data collection. Studies range from before-and-after analyses to overall congestion management. Although many different measures of effectiveness (MOEs) are often employed in these studies, travel time and speed are a fundamental aspect of the data collection. Isochronal (time contour maps), delay estimates, and average speed comparisons with the posted speed limit and using the HCM LOS values are among the most popular. Other studies have developed more unique MOEs such as a ratio comparing average peak speed to uncongested (free-flow) conditions. In addition, Appendix A contains valuable information about some of the data collection and data reduction software packages that were used in select studies. The reader is encouraged to review these sections for additional information.

3.3 Global Positioning System

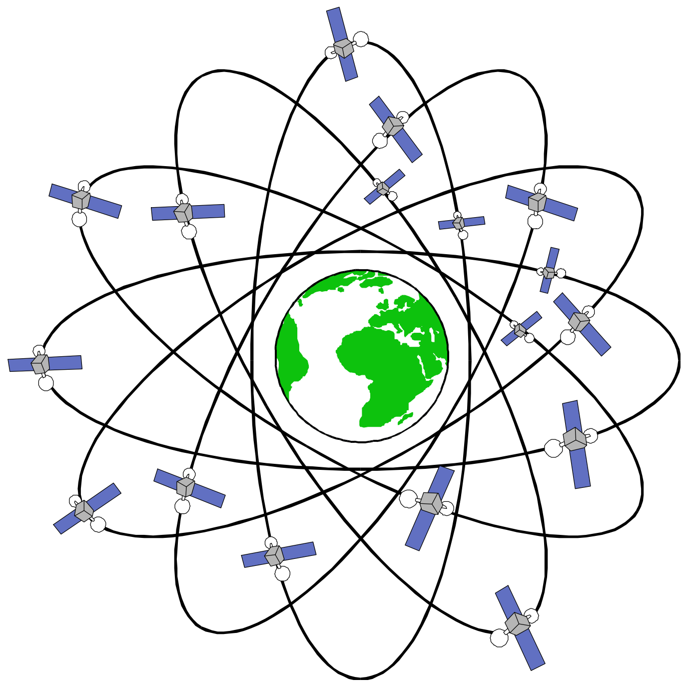
The global positioning system (GPS) was originally developed by the Department of Defense (DOD) for the tracking of military ships, aircraft, and ground vehicles. Signals are sent from the 24 satellites orbiting the earth at 20,120 km (12,500 mi) (see Figure 3-5). These signals can be utilized to monitor location, direction, and speed anywhere in the world. A consumer market has quickly developed for many civil, commercial, and research applications of GPS technology including recreational (e.g., backpacking, boating), maritime shipping, international air traffic management, and vehicle navigation. The vehicle location and navigation advantages of GPS have found many uses in the transportation profession (12).

Due to the level of accuracy that GPS technology provides, the DOD has altered the accuracy of the signal for civilian use. This is called selective availability (SA), and when it is activated precision can be degraded to about 91 meters (300 feet). In the absence of selective availability activation, accuracy can be within 18 meters (60 feet) (13). However, with the use of the differential global positioning system (DGPS), accuracy can be improved. DGPS utilizes a receiver placed at a known location to determine and correct the signal that is being provided when SA is activated. A commercial market has developed to provide differential correction hardware as well.

Many recent developments will affect the future use of GPS in civil applications. Currently, the U.S. Department of Transportation is considering the expansion of the Coast Guard marine DGPS beacon system. This includes the existing beacons utilized for DGPS along coastal areas and in the major inland waterways. However, such an expansion would provide a much broader system that would include interior areas throughout the nation (14). In addition, the Clinton administration has approved the release of the SA restrictions within the next ten years. This will provide much more accurate information for civil and commercial use (12,14).

There is also a significant market increase for in-vehicle GPS units. Japan currently holds the largest market for in-vehicle navigation systems. In 1995, the country had 60 million vehicles and there were 500,000 in-vehicle systems sold. This was up 150,000 from the previous year. In the U.S., one study showed that one-half of U.S. consumers are familiar with in-vehicle navigation systems while almost one-fifth expressed an interest in owning such a system for their vehicle (13). It is estimated that GPS in-vehicle navigation systems will not be viewed as a luxury item in the next five years (15). Current efforts to provide a world standard for in-vehicle navigation mapping will also provide compatibility between the many manufacturers in the market (16).

This section of the handbook will aid the practitioner in the use of GPS for travel time data collection. The previous experiences are included at the end of this section to provide insight into practical matters that arise when collecting data using the GPS technique. The final previous experience is in Lexington, Kentucky, and it describes the use of GPS receivers for collecting personal travel survey data. This use differs from the typical GPS test vehicle travel time data collection technique described throughout this chapter since the motorists are not trained and do not drive on specified corridors. However, there are many similarities in equipment use and data collection and analyses that are valuable to travel time data collection so it is included in this section.



Source: adapted from reference (12).

Figure 3-5. The GPS Satellite Constellation

3.3.1 Advantages and Disadvantages

Test vehicle data collection with a GPS unit has the following **advantages** (as compared to other test vehicle methods):

- Reduction in staff requirements compared to the manual method. No passenger is needed for writing (recording) information;
- Reduction in human error, including missed checkpoints or incorrectly recording information;

- GPS provides the locations. There are no checkpoints to be concerned with and there is no "starting point" problem as with the DMI method;
- No vehicle calibration is necessary as with the DMI method;
- Increased amount and variety of data available for applications including determining queue lengths, stopped delay, average speed, link speeds, detailed speed profiles, input to models for planning, emissions, or fuel consumption, and performance measure evaluation computation;
- Relatively portable and accurate;
- Provides automatic geo-coding of detailed speed data; and
- Dependent on another "proven" system. Since GPS is operated by the DOD for defense purposes, the system is monitored and maintained closely.

Test vehicle data collection with a GPS unit has the following **disadvantages**:

- Vast amount of data collected and storage requirements;
- Losing signals from the satellites due to "urban canyons" (i.e., traveling on streets adjacent to tall buildings), tunnels, trees, and power lines;
- Building or retrieving the base map;
- Equipment is generally not user-friendly as delivered. Wiring of equipment and some assembly is usually required;
- Difficult to stay updated on what equipment to purchase and what is necessary. It is a rapidly changing area;
- Requires time to learn how to set up the geographic information system (GIS) to use the incoming data. GIS software is an integral part of using the GPS system for travel time data collection efforts. GIS software is often used to display the GPS positional data on a roadway network. In addition, GIS software packages are a valuable tool for the calculation of desired measures (e.g., travel time, average speed); and
- The DOD can always disable the global positioning system when it desires.

3.3.2 Cost and Equipment Requirements

The following hardware, software, and personnel requirements are necessary for utilizing GPS for travel time data collection.

- **GPS receiver** - Required to process GPS signal information from the earth-orbiting satellites.
- **GPS antenna** - Required to receive GPS signals from the earth-orbiting satellites.
- **Differential correction receiver (if desired)** - Receives signals from land-based stations to determine corrected positional information. This information may be transmitted from a U.S. Coast Guard beacon or a private service (see differential signal service fee).
- **DGPS antenna (if desired)** - Receives signals from the land-based differential correction station.
- **Differential signal service fee** - Fee charged for the use of the FM signal or other frequency band for obtaining differential correction information. Fees vary based upon the desired positional accuracy.
- **Portable computer** - Necessary for positional data collection in the field.
- **Power supply** - Necessary for both the GPS receiver and the portable computer. Generally supplied through the cigarette lighter or a battery pack.
- **Data storage computer** - Generally located back at the office. This computer is used to store the positional data obtained in the field.
- **GPS software** - Allows for the logging of GPS information that is received from the GPS receiver.
- **GIS and compatible analyses software** - GIS software allows the positional data to be viewed on a roadway network. Compatible analysis software, generally on a GIS platform, allow for the calculation of desired speed and delay measures.
- **Test vehicle drivers** - Individuals who drive the GPS instrumented vehicles to collect travel time data.
- **Data reduction personnel** - Individuals who reduce the travel time data to prepare it for analyses.

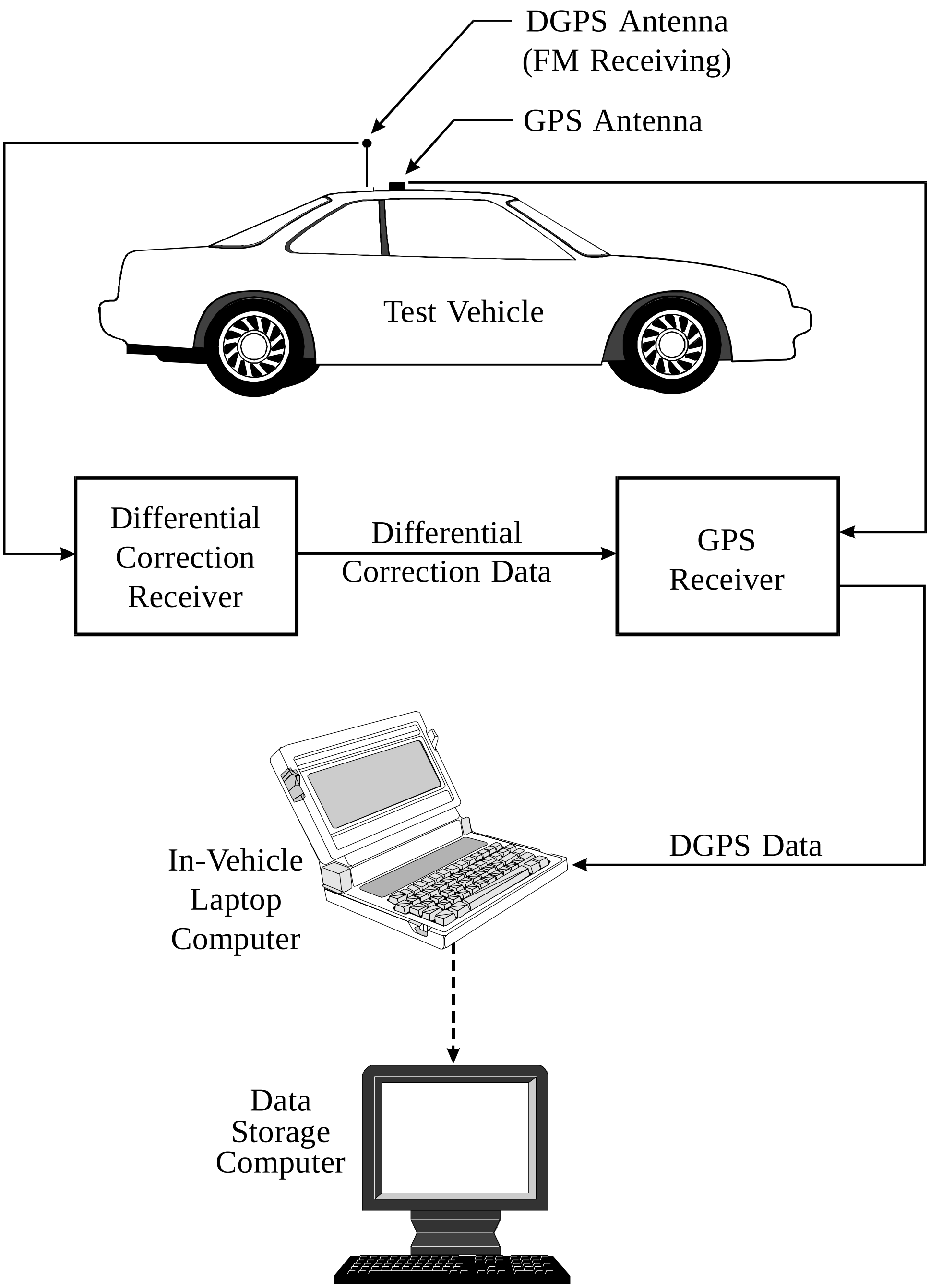
- **Supervision and management** - This includes management personnel who monitor the overall data collection, data reduction, and analysis of the data collection effort. This cost varies depending upon the scope and size of the data collection effort.

Figure 3-6 illustrates the equipment needs for GPS travel time data collection. The test vehicle is shown at the top of the page with the GPS and DGPS antennas resting on the roof of the vehicle. The DGPS antenna is connected to the differential correction receiver, and the GPS antenna is connected to the GPS receiver. The differential correction data is then transferred to the GPS receiver. The GPS receiver uses the differential correction data to correct incoming signals, and then the corrected information is output to the in-vehicle portable computer. The portable computer stores the data at user-defined time intervals as the vehicle travels down the roadway. When the travel time run is completed, the portable computer information is downloaded to a data storage computer.

Table 3-9 displays estimated costs for hardware, software, and personnel for the GPS test vehicle technique. As the technology for GPS receivers and equipment has advanced, costs have continued to decrease. In addition, with increasing accuracy, the units become more costly. The differential correction receiver also has two costs associated with it. The first cost is for the unit itself, and the second cost is for “renting” the FM signal or other frequency band from the service provider. The data storage computer is also shown in the table for completeness. However, this is generally not an added cost because an existing computer can be used for the data storage provided there is ample space on the hard drive. Since it is likely that the palmtop or portable computer may already be owned, it would not incur a cost. Generally, the cigarette lighter on the vehicle or a battery pack is used as a power source.

The GPS logging software that is listed in the table is used to record the data in an ASCII text format as it is sent from the GPS receiver. Some vendors provide proprietary software that serves this purpose. The GIS software cost estimate includes the cost of the general mapping software and a typical analysis package.

Consider the following cost estimate: Assume one would like two- to five-m (7 to 16 ft) accuracy with the use of DGPS, must purchase a palmtop computer, and already owns a computer for data storage and the necessary GIS software. The initial capital costs of the instrumentation of the vehicle is under $1,700. Vehicles can generally be appropriately instrumented for under $2,000 with this technology.



Source: adapted from reference (17).

Figure 3-6. Typical Equipment Setup for GPS Test Vehicle Technique

Table 3-9. Estimated Costs for the GPS Test Vehicle Technique

Equipment/Personnel	Unit Cost (1998 dollars)
Hardware	
GPS Receiver	$300 to $500
GPS Antenna	$100 to $150
Differential Correction Receiver (Hardware) FM Signal Service Fee: Sub-meter accuracy 2-5 meter accuracy 10-meter accuracy	$350 to $500 $700 to $800 per year per unit $200 to $300 per year per unit $70 to $100 per year per unit
DGPS Antenna	$30 to $70
Data Storage Computer	$2,000 to $3,000
Software	
GPS Logging Software	$25 to $50
GIS Software	$2,000 to $3,000
Personnel	
Test Vehicle Driver	$6 to $10 per hour
Data Reduction Personnel	$6 to $10 per hour
Supervision and Management	Varies

Considerations When Selecting Hardware and Software

This section presents issues that one may want to consider when selecting a GPS receiver and/or other elements of hardware and software for GPS travel time data collection purposes. The reader is encouraged to review Appendix A for further discussion of software for GPS travel time data collection.

- **The number of channels that the GPS unit is capable of tracking** - It has been suggested that receivers capable of tracking five or more satellites simultaneously should be considered since they provide more accuracy (18). Although only three satellites are required for two-dimensional positioning (i.e., latitude and longitude), if a satellite signal becomes obstructed it is helpful to have additional satellites being tracked (19).

- **The types and quality of the speed algorithm used within the GPS unit** - There are two methods that can be used by the GPS receiver to calculate velocity. One method is to utilize a speed averaging algorithm where changes in position and time are utilized to determine velocity. Another method calculates the velocity vectors by determining the doppler effects of the satellite signals. Since the velocity is being used to calculate distance and position information, speed data that is based upon previous points (i.e., a speed averaging algorithm) is not appropriate. A doppler-based velocity algorithm provides more accurate information (19).

- **The interface protocol between the receiver and mapping software** - The major manufacturers of GPS receivers provide a proprietary protocol for logging GPS data to the data processing software. Generally, the National Marine Electronics Association Standard 183 (NMEA 183) protocol is also included, which is based on marine navigation. This format contains many of the features applicable for travel time data collection applications along roadway segments. The software logging the GPS information must support the protocol utilized by the receiver (19).

- **The availability and quality of the base map to ensure accuracy** - The accuracy of the base map may be an important consideration depending upon the application of the data. Differential correction can be used to provide more accuracy for the travel time data. Due to the limited accuracy of some base maps that are available, the corrected GPS data may be more accurate. Travel time runs may be performed with the corrected GPS data to create the base map or a more accurate base map may be obtained. This depends on the accuracy desired and the accuracy of the GPS equipment being used. The previous experiences described in Section 3.3.5 explain different methods of establishing and using the base map.

- **User-friendly and understandable data logging software** - The logging software that is being used to record the GPS positional data is a critical element in the data collection effort. Generally, logging software is proprietary to the GPS receiver vendor or created by the user. To aid in selecting or developing data logging software, the following items are suggested:

    - *Consistent file names* - File naming should be a logical name and/or menu driven. This ensures that the files are appropriately named to include the time, date, route, direction, and facility type. This consistency allows for the automation of file naming and prevents the over-writing of data files.

- *Consider the file format that will be needed for analysis* - It is possible that a proprietary logging software will produce a file that is not in the appropriate form for necessary analysis. Without an acceptable format that can be analyzed, file conversion may be necessary. Data files should be tested to ensure that the format is compatible with analysis software to ensure that fields are not truncated and the level of accuracy is maintained.

- *Ensure a standard time is recorded on the data* - If the logging software uses Greenwich Mean Time, a configuration file that allows the user to change the time to a standard time that is easily understood may be desired. Such a configuration should be flexible enough to consider daylight savings time. Converting to a standard time is even more necessary if the data are post-processed to ensure that there is not confusion after the data are collected.

- *User-defined flags should be flexible* - There will inevitably be situations that require documentation while performing the travel time run. These include stalled cars, accidents, or rainy weather. Specific keys on the laptop keyboard should be defined that can be pressed while performing the travel time run to “flag” these situations. Ideally, the users meaning of the flag should be printed in the data file. Allowing the keys to be changeable provides flexibility depending upon what is desired to be documented in the travel time run. Further, if the messages are printed out there is not confusion when they may be changed. See page A-29 in Appendix A for an example of a flag that indicates a “Stall on Right Shoulder” in a DMI data file.

- *User-changeable questions at the end of the travel time run* - Similar to the flags described above, questions at the end of the travel time run are useful in assessing any additional incidents and/or comments that the driver may desire to document. Allowing these questions to be changeable also allows for flexibility depending upon the study scope and objectives.

3.3.3 Data Collection Instructions

The following steps should be performed before data collection starts (see Chapter 2).

1. Define the routes to be studied;
2. Define the time period during which data will be collected;
3. Determine the time interval at which GPS position data will be saved;
4. Determine the number of travel time runs that are necessary; and
5. Train test vehicle drivers with one to two of practice runs.

Training should include three aspects: 1) how to drive in the traffic stream (i.e., driving style); 2) how to operate the GPS equipment and logging software; and 3) how to ensure the equipment is ready for operation.

Once the necessary planning and preparation has been performed, the following steps should be performed in collecting the data with the GPS equipment.

1. **Install and inspect equipment**. Check the following:

    - The antennae for the GPS receiver and DGPS receiver (if applicable) should be checked that they are securely fastened to the roof of the vehicle.

    - All connections between the GPS and DGPS receivers and antennas, power supply, and portable computer should be checked to ensure they have not become unattached.

    - The communication settings (e.g., baud rates, comms port connections) for both the GPS and DGPS receivers should be checked to see that they are set correctly. This can generally be performed with the proprietary software that is supplied.

2. **Turn on equipment**. The operator then turns on the portable computer and the GPS receiver. Depending upon the software being utilized, the operator will be prompted for necessary identifying information about the travel time run. After completion of these data inputs, the portable computer should begin to display information as the data are collected. The operator should ensure that the data appear to be collecting in the appropriate manner and line-by-line data are scrolling up the screen.

3. **Prepare log sheets**. Fill out the log sheet describing the travel time including the driver's name, date, time, and other relevant information.

4. **Begin to drive the travel time route**. The driver can then begin to drive the travel time route and the GPS unit will collect the time and position information.

5. **Complete log sheet**. After the travel time run, complete the log sheet with further relevant information describing the travel time run (e.g., weather changes, incidents).

6. **Put data collection equipment away**. After shutting down the computer, place cables, antenna, and other equipment into proper storage for the next travel time run.

Upon completion of the travel time run, the portable computer can then be taken to the office for downloading the information onto a desktop computer for permanent storage. At the end of the travel time run, a log sheet may also be completed to include any details about the travel time run.

After training of personnel has been performed and the drivers are proficient in checking that the equipment is ready for data collection, the actual data collection effort is quite simple. As with the DMI method described above, the data management and storage becomes critical. This is especially true for large data collection efforts, and care must be taken to ensure the data are collected, stored, and managed carefully to optimize data storage and reduce accuracy errors.

3.3.4 Data Reduction and Quality Control

Several steps are necessary in the data reduction of GPS travel time information.

1. **Insert necessary information into the base map**. There are several input requirements to the base map that are necessary to perform reduction of the data. These inputs include street names, cross-street information, and reference (checkpoint) locations for travel time segment definition. Setting up the base map with these inputs prior to further data reduction only needs to be performed once.

2. **Convert raw log file to GIS import format**. The file that is collected from the GPS receiver and saved to the portable computer must be converted to a format that GIS can import. Files need to be converted to the format appropriate for the GIS software being used for analysis purposes.

3. **Adjust collected data to match base map (if desired)**. Apply "map matching" or appropriate software algorithms that "snap" the collected data to the base map information. It may be desired to snap all data points to the existing map to provide a common reference system for aggregation of data along the predetermined links. Some agencies then aggregate the GPS travel time data into predefined segments for further analysis. This technique reduces data storage requirements but may limit future analysis capability. Others have suggested that all GPS data points be retained to permit "dynamic segmentation" for future analyses.

UNKNOWN ??	There are differing opinions about whether to aggregate GPS data into predefined roadway segments. If data storage is available, all GPS data points should be stored to permit "dynamic segmentation."

Quality Control Considerations

Several checks can be made on the data to ensure that adequate results are being achieved. The following quality control considerations can be applied in the data reduction stages.

- **Evaluating the number of data points** - After the travel time data are brought into the GIS mapping software, the number of points provided by the GPS receiver can be checked to ensure that there are enough points covering the network. Gaps in the data indicate locations where obstructions may occur (e.g., trees, tunnels) or where the GPS receiver may be malfunctioning. This simple visual inspection can be very useful in realizing obvious errors.

  Software packages (proprietary or otherwise) generally provide a method to annotate data files for rain, construction, or other factors that may affect the travel time or accuracy of the GPS data along the corridor. These comments should be reviewed to determine possible causes of inaccurate data.

- **User-developed software techniques** - In a recent study, researchers developed a method to read the GPS receiver information into a spreadsheet to check the distances of the traveled routes to ensure they were complete (20).

- **Post-processing differential correction** - GPS data may be corrected with a post-processing method rather than utilizing DGPS in the field. Post-processing involves obtaining differential correction information after the travel time run has been performed for the time in which it was performed. Post-processing may be required for some data points even though differential correction has been applied int he field. This situation may occur if there are interruptions in the differential correction signal during data collection. The differential correction information is then applied to the collected data for correction. As the post-processing is performed, reasonableness checks can be performed to evaluate the data.

- **Perform a pilot study** - It is very important to perform a pilot study of the data collection effort. This is true for any of the test vehicle techniques. The pilot study should include every step of the data collection, reduction, and analysis process. This will ensure that the entire process can be evaluated and valuable lessons can be learned. The pilot study can provide insight into whether more or different data should be collected, the process can be automated and to what extent, and other ways that the process may be made more efficient.

3.3.5 Previous Experience

Louisiana State University

Research performed at the Remote Sensing and Image Processing Laboratory at Louisiana State University (LSU) developed a methodology to use GPS in collecting, reducing, and reporting travel time data for congestion management systems (17,21).

The data collection methodology began with the development of a base map at the interchange of I-10 and I-12 that was being studied. Since adequate base maps of the site did not exist, the base map was developed in the GIS software with the use of the data collected from the GPS units themselves. The study routes in this corridor were driven in both directions with the use of GPS to collect data every second. All entrance and exit ramps at the interchange were also driven to ensure all portions of the interchange were included. In addition, ramps, lane drops, and signalized intersections were included (21).

The next step in the methodology was the determination of checkpoints along the route since travel time and average speed studies generally average these measures over a specific link length. Two rules were used in the establishment of the checkpoint locations. The first was to establish a checkpoint at all physical discontinuities (e.g., signalized intersections, significant unsignalized intersections, lane drops, exit ramps, entrance ramps, other geometric discontinuities). The second guideline used in the determination of checkpoints was a nominal spacing of five checkpoints every mile. This resulted in 2,397 segments with an average segment length of 0.21 km (0.13 mi) (17,21).

After the determination of the checkpoint locations, it was important to link each of the segments to a relational database. The use of a unique identifier for each segment allowed for associating the number of lanes and posted speed limit to each section. In addition, analyses performed over different dates and times could be associated with specific segments (21).

Travel time data were collected in the morning and afternoon peak hours as well as during off-peak periods. To aid in the data reduction effort, a data reduction software macro was developed. The macro aids in transforming the GPS point-by-point data into travel times and average speeds over the segment. When the user clicks on a specific segment along the corridor, the data reduction application recognizes the segment and determines entrance and exit times and updates the user interface (21).

This methodology was used to collect travel time on 531 km (330 mi) of urban highways in three metropolitan areas in Louisiana: Baton Rouge, Shreveport, and New Orleans. The travel time data included 183,000 segment travel time and speed records derived from approximately 2.9 million GPS points collected on 48,279 km (30,000 mi) of travel time runs. The study found that undergraduate students could be trained to perform the data reduction in one to two hours and were proficient with the process within ten hours. As a general rule, they found that data could be reduced about eight times faster than it was collected (i.e., a two hour data collection run would take 15 minutes to reduce to segment identifiers, route travel time, and average speed) (21).

The LSU researchers concluded that using GPS technology was efficient and cost-effective in measuring travel time and average speed along the corridor. The GPS technology was found to provide an accurate depiction of the test vehicle's location and speed (17,21). An additional benefit of the LSU research was the graphical output and presentation methods with the data. These methods are further discussed in Chapter 7, which describes different data summary and presentation techniques.

Central Transportation Planning Staff (CTPS), Boston, Massachusetts

Travel time was identified as a performance measure for the Boston area's congestion management system (CMS). Several data collection techniques for travel time data were considered, but GPS was selected for use. GPS was the selected method since it provided the high potential for more accurate data at a reduced cost. Further, the Central Transportation Planning Staff in Boston selected the GPS technology since it allows for the collection of an increased amount of data (i.e., collected every second) that may be utilized for analyses of queue lengths, stopped delay, and speed profiles for the CMS (20).

Several months went into the development of an interface in the GIS software to allow for standardizing the editing process of the data collected with the GPS receivers. The menu within the GIS software allows for the calculation of key performance measures such as travel time and average speed along predetermined segments. A file is then produced that contains characteristics of the segment including the route, date, segment name, segment start and end times, segment length, and average speed for every segment in which GPS data were collected (20).

The study also compared data collection utilizing the manual method with the GPS method. These techniques were compared on one segment. The traditional manual method that was used employed a passenger in the test vehicle who wrote down the time as they reached predetermined checkpoints. The information was then entered into a spreadsheet to calculate travel times and speeds.

Data was collected with GPS units in one-second increments and included longitude, latitude, time, altitude, and other information. A passenger/recorder was not necessary when collecting data in this manner. The study found that there was general agreement between the traditional manual method and the GPS technology. The differences in distance between segments was less than 0.16 km (0.1 mi) and all the speeds were within 8 km/h (5 mph) (20).

It is interesting to note that differential correction was not used for the GPS travel time data collection in this study. Since the study was only interested in determining average speeds along the corridor, those performing the study were not concerned that the points match exactly to the base map. Therefore, differential correction was not used in the study. Quality control checks such as viewing each data collection run in the GIS map environment, and viewing the data in spreadsheet form allowed the research team to realize if the data were suspect. The CTPS staff in Boston have been very pleased with the use of the GPS technology for travel time data collection.

Texas Transportation Institute (TTI), San Antonio, Texas

The Texas Department of Transportation (TxDOT) is sponsoring the Texas Transportation Institute (TTI) in using GPS technology for travel time data collection in San Antonio. The study will use GPS data collection to provide an historical database of travel time information for approximately 241 centerline km (150 centerline mi) of freeway and arterial roadways in San Antonio. The data will be used for the Model Deployment Initiative (MDI) that is underway in San Antonio.

Palmtop computers are being used in the study to collect the GPS travel time data. Differential correction is also being used to add accuracy to the data collection effort. Figure 3-7 contains a diagram of the equipment used in the study. The GPS data logging software developed by TransCore is also being used. Figure 3-8 shows a sample of the data being collected and recorded at one-second intervals along the travel time routes. The logging software records the latitude, longitude, day, time, speed, direction, GPS rating, and user flags. The direction is measured in degrees from true North increasing eastwardly. The GPS rating represents whether the data is new (equal to one) or old. Generally the output data are new except when the machine is warming up and when there are interruptions in the data stream. When the machine is first warming up and not moving, old data are used to determine location information.

The final column for user flags represents user-specified flags that have been predefined. For example, the "s" in Figure 3-8 represents signals along the arterial route. The data logging allows for defining different keys to represent different environmental or traffic situations or for marking the endpoints of the travel time run (e.g., s = signals, c = construction, r = rain, e = end of run, b = beginning of run). The driver of the test vehicle can simply press the predetermined key on the keyboard of the portable computer to mark the location in the travel time run to annotate the data.

Figure 3-9 shows a sample of a field data collection form that is being used in the study to record start times, file names, incidents, and environmental conditions during the travel time run. This form provides a location for recording up to six travel time runs for a given direction in the peak period. The study is expected to perform at least five travel time runs in each peak period. Note that the form also contains a shaded region at the bottom that confirms when the file has been downloaded to the data storage computer.

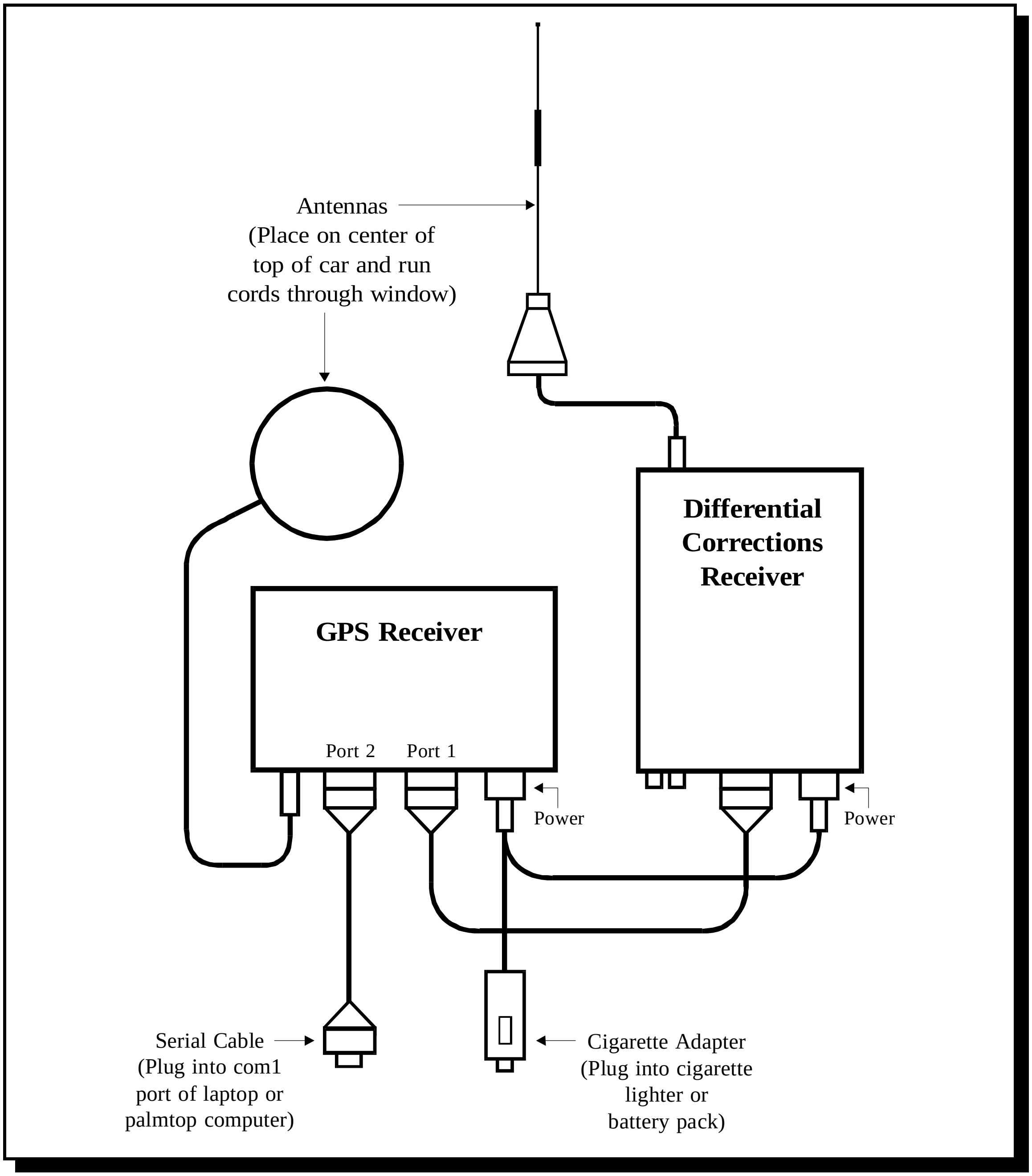


Figure 3-7. Equipment Used for GPS Data Collection in San Antonio, Texas

Latitude	Longitude	Day	Time	Speed	Direction	GPS Rating	User Flag
29.52574	-98.538	Thu	19:38:08.0	11	-132	1	
29.52571	-98.538	Thu	19:38:09.0	13	-133	1	
29.52567	-98.5381	Thu	19:38:10.0	15	-136	1	
29.52562	-98.5381	Thu	19:38:11.0	16	139	1	S
29.52557	-98.5352	Thu	19:38:12.0	17	-139	1	
29.52551	-98.5382	Thu	19:38:13.0	19	-139	1	
29.52544	-98.5383	Thu	19:38:14.0	21	-140	1	
29.52537	-98.5384	Thu	19:38:15.0	23	-140	1	
29.52534	-98.5384	Thu	19:38:16.0	24	-140	1	
29.52522	-98.5385	Thu	19:38:17.0	26	-141	1	
29.52514	-98.5386	Thu	19:38:18.0	26	-141	1	
29.52509	-98.5386	Thu	19:36:19.0	26	-140	1	S
29.52497	-98.5387	Thu	19:38:20.0	27	-140	1	
29.52493	-98.5388	Thu	19:38:21.0	26	-140	1	
29.52476	-98.5389	Thu	19:38:23.0	27	-135	1	
29.52472	-98.539	Thu	19:38:23.0	27	-138	1	
29.52463	-98.5391	Thu	19:38:24.0	25	-138	1	
29.52454	-98.5392	Thu	19:38:25.0	28	-135	1	
29.52444	-98.5393	Thu	19:38:26.0	29	-140	1	
29.52436	-98.5393	Thu	19:35:27.0	30	-135	1	
29.52425	-98.5394	Thu	19:38:28.0	30	-139	1	
29.52417	-98.5395	Thu	19:35:29.0	31	-135	1	
29.52403	-98.5397	Thu	19:38:31.0	30	-140	1	
29.52397	-98.5397	Thu	19:38:31.0	30	-137	1	
29.52389	-98.5398	Thu	19:38:32.0	31	-138	1	
29.52378	-98.5399	Thu	19:38:33.0	32	-136	1	
29.5237	-98.540	Thu	19:38:34.0	32	-139	1	
29.52355	-98.5401	Thu	19:38:36.0	33	-140	1	
29.52348	-98.5402	Thu	19:38:36.0	34	-138	1	

Figure 3-8. Sample Data from Data Logging Software

Driver: ______________________________________

Date: ______________________________________

AM

Route: BANDERA / CULEBRA

Direction: SE (IH-410 to IH-10)

	Start Time:	**Start Time**:	**Start Time**:	**Start Time**:	**Start Time**:	**Start Time**:
	File: Trip ___.gps	**File**: Trip___.gps	**File**: Trip___.gps	**File**: Trip ___.gps	**File**: Trip___.gps	**File**: Trip___.gps
Route Section Limits	**Incident Type (if any)**					
IH 410 to Callaghan						
Callaghan to Skyview						
Skyview to Hillcrest						
Hillcrest to Ligustrum						
Ligustrum to Cheryl						
Cheryl to Gen. McMullen						
Gen. McMullen to 24th						
24th to 19th						
19th to Zarzamora						
Zarzamora to IH 10						
Incident Types 1 - Accident Lane 1 (inside lane) 2 - Accident Lane 2 (middle lane) 3 - Accident Lane 3 (outside lane) O - Accident in Opposite Direction L - Stall on Left Shoulder R - Stall on Right Shoulder M - Multiple Lanes Blocked CS - Construction Start CE - Construction End D - Debris in Road Q - Queue SQ - Signal Queue	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No	**Weather** ☐ Clear ☐ Overcast ☐ Lt. Rain/Drizzle ☐ Heavy Rain **Light** ☐ Normal Daylight ☐ Dark or Twilight ☐ Sun Glare ☐ Fog **Pavement** ☐ Dry ☐ Wet ☐ Ice/Slickness **Any Incidents?** ☐ Yes ☐ No

OFFICE USE ONLY					
File Downloaded? ☐ Yes, Init.______ ☐ No **File Name:** ______________	**File Downloaded?** ☐ Yes, Init.______ ☐ No **File Name:** ______________	**File Downloaded?** ☐ Yes, Init.______ ☐ No **File Name:** ______________	**File Downloaded?** ☐ Yes, Init.______ ☐ No **File Name:** ______________	**File Downloaded?** ☐ Yes, Init.______ ☐ No **File Name:** ______________	**File Downloaded?** ☐ Yes, Init.______ ☐ No **File Name:** ______________

Figure 3-9. Field Data Log Form Used for GPS Data Collection in San Antonio, Texas

TransCore

TransCore (formerly known as JHK & Associates) has been extensively involved in the use of GPS technologies for transportation applications through research sponsored by the Federal Highway Administration (FHWA). A recent study in Northern Virginia investigated all aspects of the GPS travel time data collection effort including data processing and analysis. The study incorporated the use of data smoothing, map matching, path building, and data assimilation techniques to determine the travel time information along several routes. TransCore performed an alternatives analysis along a 64 km (40 mi) section of Route 1 between Prince William County and the Capital Beltway (I-95). Several parallel arterial and freeway segments were included. Data were collected with approximately 190 GPS travel time runs with two GPS units for a two week period during the morning and evening peak periods in both directions. The following objectives were established for the data collection technique to be used (19,22):

- Quantify roadway performance in ways the general public can understand;
- Quantify traffic flow characteristics for problem location and model calibration; and
- Determine the dynamics and precise location of traffic congestion.

The GPS technology was selected for the travel time data collection for the following reasons (19).

- **Less labor intensive than other methods** - This enabled the study budget to accommodate better coverage (both in time-of-day and facilities) and increase the number of observations per roadway.

- **Equipment was simple to use and portable** - This made it possible to involve a larger number of staff members, which, in turn, provided the vehicle and driver the flexibility needed to schedule early morning and late evening data collection runs.

- **Provided automatic geo-coding of detailed speed information** - This made it possible to analyze detailed traffic flow characteristics without significant investment in staff time and resources that would be required to apply traffic simulation tools.

- **Relatively inexpensive** - Savings were realized at a number of points in the analysis process. Data collection is the most obvious, but savings were also recognized in map production, graphics presentation, data analysis, data summary, problem identification, and level of service analysis.

Network map matching was an important aspect of this study. Since differential correction was not used and travel time information for each link was desired, algorithms were developed that would shift the points to the network map. Census TIGER files were used in concert with the GPS Data Logging Software developed by TransCore. The study concluded that map matching, which includes data smoothing and shape matching algorithms, is a useful tool when it is desired to match the GPS data to the network map.

Map matching algorithms cannot simply assign data collected with GPS receivers to the nearest roadway link. This causes the points to "jump" from the roadway to the cross street and back to the roadway as the collected points pass through an intersection. Including the direction of travel into the algorithm may reduce the likeliness of this problem. In order to eliminate the problem, the map matching algorithm must match a group of points to the base map, not individual data points (19).

The use of data smoothing and shape matching algorithms is also important. The smoothing algorithm compares the individual data points to groups of points to ensure they are aligned correctly. For example, if a group of data points have an eastbound orientation and one individual point is oriented north, the algorithm will orientate the northbound point to match the group with the eastbound orientation (19). The shape matching algorithm is used to fit GPS data to corners and curves on the roadway network. After a corner or curve is identified, the algorithm fits the set of GPS data to the network coordinates. The TIGER files represent roadways connected at sharp angles, while the GPS data is collected as a smooth series of points. The data smoothing and shape matching algorithms must recognize the smooth curve in the GPS data as a turn and convert it into a sharp-angled turn for matching to the map network (19).

A path-tracing algorithm was also a valuable component for network matching. If the network is not accurate, the GPS data does not include right-angle turns, or the grid is too dense and contains a large number of similar shapes, additional problems with map matching can occur. The path-tracing algorithm identifies the most likely location for GPS data when a particular movement as shown in an individual GPS data point cannot be made. The points prior to this individual point are reassigned to a new path until a common match is found between the network and the GPS data. In addition, the path-tracing algorithm considers traffic prohibitions (e.g., one-way streets, freeways, and intersections with turn restrictions) (19).

Finally, TransCore's experience indicated that it is sometimes necessary to break up the collected GPS data into different paths. This may be necessary due to an incomplete network or the possibility that the GPS data collection vehicle left the travel run corridor by going into a driveway or parking lot. In these cases the map matching could be terminated until the vehicle re-enters the corridor in which data are being collected. Although this feature is quite useful, TransCore points out that this adds significantly to the complexity of the algorithm (19).

The TransCore experience demonstrates the capability of map matching algorithms. Although it is generally not necessary to snap every data point to the existing network map, this does provide a network referencing system for additional applications. It may be desirable to snap all data points to the existing map to provide a common reference system for aggregation of data along the predetermined links. An automated procedure that performs map matching as described above is useful for these applications (e.g., performance measure calculation).

Lexington, Kentucky (GPS for Personal Travel Surveys)

The experience explained here was primarily for the collection of personal travel survey data using GPS, but travel time data were collected as well. Travel times of interest in most personal travel surveys are typically at a trip level (i.e., from trip origin to destination). It differs from the typical GPS test vehicle applications described throughout this chapter because the drivers are not trained and they are not restricted to drive on specified corridors. However, the discussion is appropriate in this section because practitioners can gain valuable insight from the conclusions and experience of this research effort since the vehicles are instrumented in a manner similar to traditional test vehicle techniques. Further, data reduction and analysis are performed similarly through the use of a GIS platform.

Transportation planners and policy-makers are often concerned about personal travel and changes in personal travel. A recent study has been performed to utilize the benefits of GPS technology in the collection of personal travel surveys (20). The personal travel surveys included the collection of data relating to trip purpose and frequency, as well as overall trip times. The Federal Highway Administration sponsored the study with the cooperation of the Lexington Area Metropolitan Planning Organization (MPO). The three primary objectives of the study are as follows:

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

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

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

To meet these objectives, sampling of listed telephone numbers was performed and 100 households were selected for the study. The Lexington Area (MPO) covers the counties of Fayette and Jessmine over approximately 1195 sq. km. (461 sq. mi.) and a population near 350,000 persons. An automatic data collection process was utilized to collect data in this study area by using a GPS receiver, personal travel survey software that allows the recording of important travel characteristics (e.g., identifying driver or passengers), palm-top computer, memory card, and connecting cables. Differential correction of the GPS data was not performed. At the trip start, the motorists recorded travel information including identifying the driver and passenger(s) and their trip purpose(s). A GIS platform was used to analyze and investigate the results of the travel patterns.

Overall, the project was rather successful in achieving the objectives described above. The first objective above is based on technology aspects of the hardware and software. The study found that the relatively low-cost and portable GPS equipment was responsive to the technology and it could be shipped to users for self-installation and operation. The touch-screen interface was used and was also received well, even with the older population. Map-matching techniques were also successfully used to match the GPS data points to the GIS map.

The second objective stated above is based upon the advantages and disadvantages between self-reported travel and the data reported from the GPS units. Traditionally, personal travel surveys are performed with telephone or mail-back surveys, but the technology described here allows the motorist to record trip information in the vehicle through the touch-screen interface. This computer-assisted self-interviewing (CASI) technique routinely collects data (e.g., trip start and end times, trip distances, route choice, origin/destination, travel speed, and functional class) with more accuracy. Much of this information can be easily viewed and determined with the aid of the GIS platform. Recall interviews were performed inquiring about previous personal trip information, and it was found that 61.4 percent of the recall trips were matched to the GPS information collected. “Matching” entailed comparisons between recall trip start times and durations compared to the personal digital assistant (PDA) within an established range and professional judgement about trip characteristics being matched.

The final objective addresses the future potential of the technology for studies of this sort. The study found that the GPS technology is quite successful and that motorists are accepting of the technology. The research team expresses the advantages of travel data collection with the aid of GPS receivers and technology. The need for future standardization of hand-held computer operating systems and GPS PCMCIA cards is mentioned. It is further noted that GPS use in transportation is a relatively new area and that more work is needed in identifying transportation needs and data users for integration into GIS and GPS hardware and software. This would aid the test vehicle application discussed in this chapter and in section 5.5. Additionally, it is noted that although the use of a PDA in conjunction with the GPS receiver may be desirable in some cases, written trip diaries can still be used if budgets do not permit the acquisition of PDA units.

The research team also notes that the visibility and contrast of the computer touch-screen should be a key consideration. The contrast of the screen did cause difficulty for some respondents. The questions themselves that are prompted on the computer must be very understandable, along with a user-friendly system, to ensure that the data are reliable. Finally, some complaints were received about the large amount of sometimes cumbersome cabling. This could be greatly reduced if the GPS antenna can be placed inside of the vehicle. Further, for a large-scale deployment, the research team suggests sturdier and harder equipment.

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3.5 Additional Resources for Test Vehicle Techniques

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See Chapter 5 for further GPS references that relate to ITS probe vehicle techniques.