1 INTRODUCTION

Travel time, or the time required to traverse a route between any two points of interest, is a fundamental measure in transportation. Travel time is a simple concept understood and communicated by a wide variety of audiences, including transportation engineers and planners, business persons, commuters, media representatives, administrators, and consumers. Engineers and planners have used travel time and delay studies since the late 1920s to evaluate transportation facilities and plan improvements. Commuters use a “travel time budget,” theorized to be between 20 and 30 minutes per one-way commute, to locate their housing relative to work locations. The media report travel times and delays on urban freeways and streets with language like “. . . an accident on the northbound lanes of the Beltway has traffic delayed 10 to 15 minutes . . .”

A renewed interest in travel time studies in the 1990s may be attributed to several factors:

- **Congestion management systems**, mandated by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, commonly use travel time-based performance measures to evaluate and monitor traffic congestion.

- **A changing analytical and funding environment** requires that certain transportation analyses (e.g., major investment studies) compare different transportation modes for a common funding source. Travel time is a common element among all transportation modes.

- **Increasing involvement in transportation decisions** by non-technical persons (e.g., politicians, advocacy groups, and the general public) requires analytical techniques and measures that are simple and easy to understand, yet rigorous enough for technical analyses. Travel time-based measures and analyses meet both of these needs.

1.1 Objective of the Handbook

The primary objective of this handbook is to provide guidance to transportation professionals and practitioners in the collection, reduction, and reporting of travel time data. The handbook should be a useful reference for designing travel time data collection efforts and systems, performing travel time studies, and summarizing travel time data. The handbook does not constitute a standard, specification, or regulation, but instead serves as a compilation of experience and information. Agencies new to travel time data collection may wish to adopt sections of the handbook as standard procedures, whereas other agencies with time-tested procedures and experience may wish to incorporate specific details or criteria.

This handbook also introduces the wide variety of uses for travel time data, but does not contain specific guidance or instructions on data analyses. A companion "Travel Time Applications" handbook also developed at the Texas Transportation Institute (TTI) focuses on travel time data applications and provides more comprehensive discussions with specific examples.

IMPORTANT ☞ The primary objective of this handbook is to provide guidance in the collection, reduction, and reporting of travel time data. A companion handbook focuses on travel time data applications.

1.2 Handbook Organization

The handbook is organized into the following seven chapters:

- **Chapter 1, Introduction** - contains an overview of the handbook and an introduction to the basic concepts and techniques used to collect travel times.

- **Chapter 2, Developing and Implementing a Data Collection Plan** - provides general guidance in creating and using a travel time data collection plan. Answers are provided to common questions like: "What data collection technique should I use?", "On what days and at what time should I collect data?", and "How do I sample travel times over time and space?"

- **Chapter 3, Test Vehicle Techniques** - provides instructions for collecting travel time data using active test vehicles in combination with varying levels of instrumentation: manual (clipboard and stopwatch), an electronic distance-measuring instrument (DMI), or a global positioning system (GPS) receiver.

- **Chapter 4, License Plate Matching Techniques** - provides instructions for collecting travel times by matching vehicle license plates between consecutive checkpoints with varying levels of instrumentation: tape recorders, video cameras, portable computers, or automatic license plate character recognition.

- **Chapter 5, ITS Probe Vehicle Techniques** - provides guidance on obtaining travel times using intelligent transportation system (ITS) components and passive probe vehicles in the traffic stream equipped with signpost-based transponders, automatic vehicle identification (AVI) transponders, ground-based radio navigation, cellular phones, or GPS receivers.

- **Chapter 6, Emerging and Non-Traditional Techniques** - includes information about several techniques that are currently being researched or tested. Emerging techniques include the use of inductance loop detectors, weigh-in-motion stations, and video cameras for collecting or estimating travel times.

- **Chapter 7, Data Reduction, Summary, and Presentation** - contains information about the reduction, summarization, and presentation of travel time data and provides many examples of tabular and graphical summaries.

1.3 Existing Guidelines

Several existing guidelines for travel time studies have been incorporated into this handbook. Guidelines produced by Berry and Green (1), Berry (2), and the National Committee on Urban Transportation (3) in the 1950s provided the foundation for travel time studies. The Institute of Transportation Engineers' (ITE) *Manual of Transportation Engineering Studies* (4) serves as a standard reference on travel time studies for many transportation engineers. The *1994 Highway Capacity Manual* (5) contains guidance for conducting travel time studies to evaluate quality of traffic flow for arterial streets. Volume II of NCHRP Report 398, *Quantifying Congestion: User's Guide* (6) provides guidance related to selecting and applying travel time-based measures for quantifying congestion and describes the steps and procedures for collecting travel time data.

Many of these guidelines, however, focus on the test vehicle technique and provide little information about newer data collection techniques or sampling procedures. This handbook is intended to be comprehensive and fill the gaps in existing travel time data collection guidelines. The handbook also contains information about emerging techniques that may substantially reduce the costs of collecting travel time data. The next section contains an overview of the data collection techniques that are addressed in this handbook.

1.4 Overview of Techniques

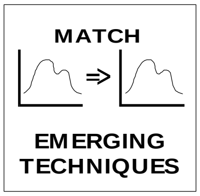
Several data collection techniques can be used to measure or collect travel times. These techniques are designed to collect travel times and average speeds on designated roadway segments or links. Because these techniques differ from point-based speed measurement, the resulting travel time and speed data are much different than spot speeds. A general overview of the various techniques is provided in the following paragraphs.

IMPORTANT ☞ The handbook contains four categories of travel time data collection techniques: test vehicle (Chapter 3), license plate matching (Chapter 4), ITS probe vehicle (Chapter 5), and emerging and non-traditional techniques (Chapter 6).

Test vehicle techniques (often referred to as "floating car") are the most common travel time collection methods and consist of a vehicle(s) that is specifically dispatched to drive with the traffic stream for the express purpose of data collection. Data collection personnel within the test vehicle control the speed of the vehicle according to set driving guidelines ("average car", "floating car", or "maximum car": see Chapter 3 for more details). A passenger in the test vehicle can manually record travel times at designated checkpoints using a clipboard and stopwatch, or computer instrumentation may be used to record vehicle speed, travel times or distances at preset checkpoints or intervals. An electronic DMI attached to the vehicle's transmission can be coupled with a portable computer to record speeds and distances traveled up to every half-second or less. A GPS receiver coupled with a portable computer can be used to record the test vehicle's position and speed at time intervals as frequent as every second.

License plate matching techniques consist of collecting vehicle license plate characters and arrival times at various checkpoints, matching the license plates between consecutive checkpoints, and computing travel times from the difference between arrival times. License plate matching for travel times can be performed in a number of different ways. The manual method involves recording license plate characters using voice tape recorders, then later transcribing the license plates into a computer for subsequent matching. A portable computer-based method relies on human observers to transcribe the license plate numbers into the computer in the field, then match the license plates by computer at a later time. Video cameras or camcorders can be used to collect license plates with manual transcription into a computer being performed by humans at a later date. A video and character recognition-based method collects license plate images using video, and relies on character recognition software to recognize and automatically transcribe the license plate number for subsequent computer matching.

ITS probe vehicle techniques utilize passive instrumented vehicles in the traffic stream and remote sensing devices to collect travel times. The ITS probe vehicles can be personal, public transit, or commercial vehicles and often are not driving for the express purpose of collecting travel times. ITS probe vehicles also typically report travel time data to a transportation management center (TMC) in real-time. Probe vehicles may be equipped with several different types of electronic transponders or receivers. A signpost-based system, typically used by transit agencies for tracking bus locations, relies on transponders attached to roadside signposts. AVI transponders are located inside a vehicle and are used in electronic toll collection applications. Ground-based radio navigation systems use triangulation techniques to locate radio transponders on vehicles, and are used in route guidance and personal communication systems. The monitoring of cellular telephone activity is also being tested for potential travel time collection applications. GPS receivers use a network of 24 satellites to determine vehicle position and are becoming common for route guidance and "mayday" security applications.



Emerging and non-traditional techniques are currently being researched or developed, or may be considered non-traditional when compared to existing methods. These techniques use a variety of methods, such as inductance loops, weigh-in-motion stations, or aerial video to estimate or calculate travel times. Most of the emerging techniques are currently in developmental or testing stages and have not been extensively field-tested or applied. The experience with these emerging techniques is provided for the reader's information. Future editions of this handbook may include more detailed information on these emerging techniques as they develop and mature.

1.5 Travel Time and Speed Definitions

Travel time is broadly defined as "the time necessary to traverse a route between any two points of interest." Travel time can be directly measured by traversing the route(s) that connects any two or more points of interest. Travel time is composed of *running time*, or time in which the mode of transport is in motion, and *stopped delay time*, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped, i.e., typically less than 8 kph, or 5 mph). Figure 1-1 illustrates the concepts of running time and stopped delay time.

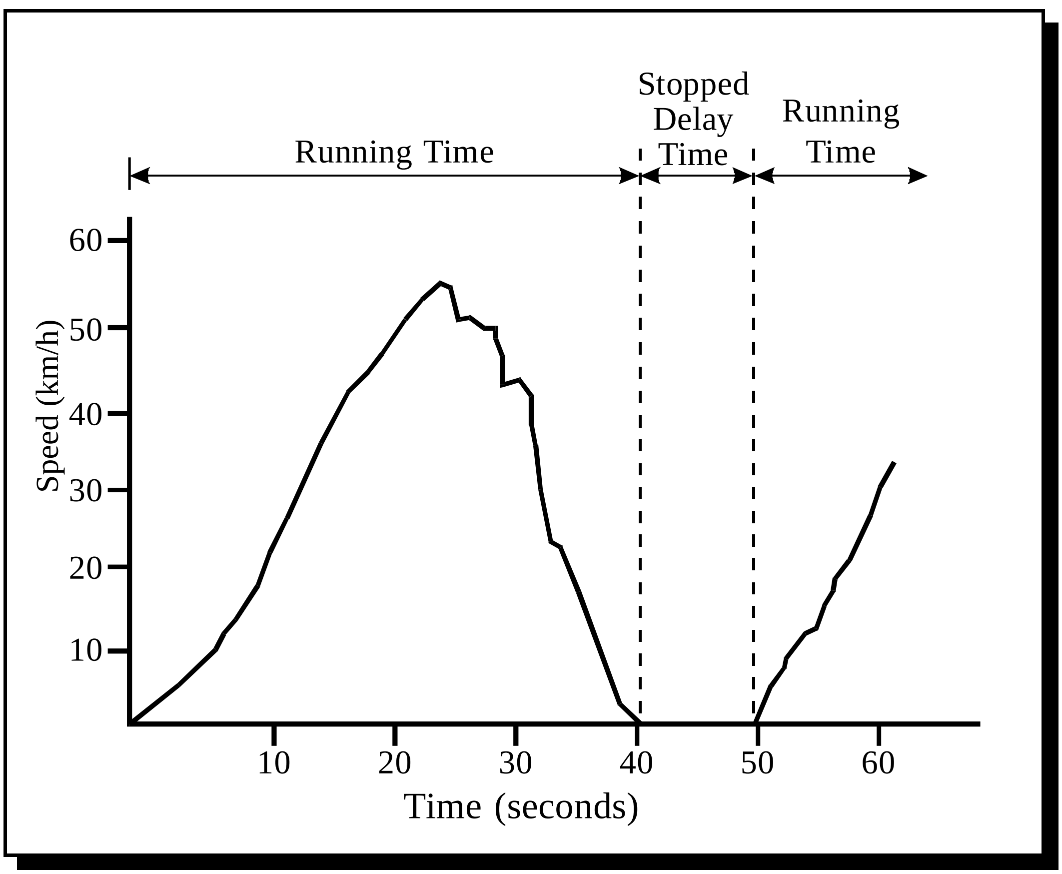


Figure 1-1. Illustration of Running Time and Stopped Delay Time

Travel time can also be estimated in certain cases by assuming the average speed at a particular point (spot speed) is constant for a relatively short distance (typically less than 0.8 kilometer, or 0.5 mile). The assumption of consistent speeds over a short roadway segment is most applicable to uninterrupted flow facilities (e.g., freeways or expressways) with stable traffic flow patterns. The estimated travel time can be computed using the average spot speed, or time-mean speed, and the roadway segment length (Equation 1-1).

Average or mean travel times are computed from individual travel times by using standard statistical formulas or computer software. The reader is reminded that the computed average travel time is only an estimate for the entire population of vehicles or persons that traveled the designated roadway during the time period of interest.

Speed values can be calculated using travel times, but there are several types of speeds that should be distinguished (7). The **time-mean speed** is the arithmetic average speed of all vehicles for a specified period of time (Equation 1-2). For example, dual inductance loop detectors in traffic management systems are typically configured to report a time-mean speed at 20-second intervals.

The **space-mean speed** is the average speed of vehicles traveling a given segment of roadway during a specified period of time and is calculated using the average travel time and length for the roadway segment (Equation 1-3). For example, transponder-based probe vehicle systems collect travel times between instrumented locations and an average travel time is computed from individual probe vehicle travel times. The space-mean speed is then calculated by dividing the distance between instrumented locations by the average travel time. The time-mean speed is associated with a point over time, whereas the space-mean speed is associated with a section of roadway. In nearly all cases involving the calculation of average speeds from individual travel times, the space-mean speed should be used. Time-mean speeds are most commonly used in reference to a single point along a roadway and averaged over a time period (e.g., loop detectors and other point detection devices). Equation 1-5 shows the relationship between time-mean speeds and space-mean speeds.

CAUTION
!!

Time-mean speed is associated with a single point along a roadway over time, whereas the space-mean speed is associated with a specified length of roadway. Use space-mean speeds when reducing and analyzing travel time data.

Average running speeds can be calculated by using the average running time, which does not include any stopped delay time (Equation 1-4). If there is no stopped delay, the average running speed is equal to the space-mean speed. Running speeds may be appropriate if one does not want to include any stopped delay along a route, such as stopped delay due to traffic signals on an arterial street. Table 1-1 contains an example of the calculation of these different speed parameters using travel times as input. The table illustrates the calculation of space-mean and time-mean speeds and shows the difference between the two speed values to be approximated by Equation 1-5.

$$\text{Estimated Travel Time (seconds)} = \frac{\text{Segment Length (km)}}{\text{Time-Mean Speed (km/h)}} \times \text{(3,600 sec/hour)} \qquad (1\text{-}1)$$

$$\text{Time-Mean Speed, } \bar{v}_{TMS} = \text{avg. speed} = \frac{\sum v_i}{n} = \frac{\sum \frac{d}{t_i}}{n} \qquad (1\text{-}2)$$

$$\text{Space-Mean Speed, } \bar{v}_{SMS} = \frac{\text{distance traveled}}{\text{avg. travel time}} = \frac{d}{\frac{\sum t_i}{n}} = \frac{n \times d}{\sum t_i} \qquad (1\text{-}3)$$

$$\text{Average Running Speed, } \bar{v}_r = \frac{\text{distance traveled}}{\text{avg. running time}} = \frac{d}{\sum \frac{t_{ri}}{n}} = \frac{n \times d}{\sum t_{ri}} \qquad (1\text{-}4)$$

where:
- d = distance traveled or length of roadway segment;
- n = number of observations;
- v_i = speed of the *i*th vehicle;
- t_i = travel time of the *i*th vehicle; and
- t_{ri} = running time of the *i*th vehicle.

$$\bar{v}_{TMS} \approx \bar{v}_{SMS} + \frac{S^2_{SMS}}{\bar{v}_{SMS}} \qquad (1\text{-}5)$$

where:
- $\bar{v}_{TMS}$ = sample time-mean speed;
- $\bar{v}_{SMS}$ = sample space-mean speed; and
- S^2_{SMS} = sample variance of the space mean speed.

Table 1-1. Comparison of Time-Mean and Space-Mean Speeds

Data Items	Run 1	Run 2	Run 3	Run 4	Run 5	Sum	Average	Variance
Travel Time (sec)	153	103	166	137	127	686	137.2	
Running Time (sec)	142	103	141	137	127	650	130.0	
Stopped Delay Time (sec)	11	0	25	0	0	36	7.2	
Average Travel Speed (km/h)	44.7	66.4	41.2	49.9	53.9	256	51.2	95
Average Running Speed (km/h)	48.1	66.4	48.4	49.9	53.9	n.a.	52.6	

Section Length = 1.9 km

Difference between Time-Mean Speed and Space-Mean Speed
Time-Mean Speed = ∑(speeds) / no. of runs = 256 / 5 = 51.2 km/h
Space-Mean Speed = no. of runs × distance / ∑ (travel times) = 5 x 1.9 / 686 = 49.8 km/h
Therefore, difference = 1.4 km/h

Check Equation 1-5: Time-Mean Speed ≈ 49.8 + 95 / 49.8 ≈ 51.7 km/h ≈ 51.2 km/h

In simple terms, the space-mean speed is the distance traveled divided by an average travel time, whereas the time-mean speed is an average of individual vehicle speeds. Space-mean speeds weight slower vehicles' speeds more heavily, as the slower vehicles are within the segment of interest for a longer period of time.

In mathematical terms, the space-mean speed is also known as a harmonic mean speed. Wardrop (8) developed a relationship between time-mean speed and space-mean speed, which is shown as Equation 1-5 (9). The equation indicates that time-mean speed is only equal to the space-mean speed when the space-mean speed variance is equal to zero (i.e., all vehicles in the traffic stream travel at the same speed). For all other cases when the space-mean speed is greater than zero, the time-mean speed will always be greater than the space-mean speed. The space-mean speed is statistically more stable than the time-mean speed, particularly for short roadway segments or small travel times. Typically, the differences between time-mean speed and space-mean speed are about 1 to 5 percent, or about 1.6 km/h (1 mph) over a range of speeds (10). Numerical simulation shows that the difference between these two speed values become less discernable as speeds increase.

1.6 Direct Measurement Versus Estimation

Transportation analyses use data from two fundamental sources:

- Data that is **directly collected or measured** in actual traffic conditions; and
- Data that is **estimated** through the use of computer simulation models or surrogate estimation techniques.

Figure 1-2 illustrates the relationship between these sources of data in transportation analyses. As indicated in the figure, one may use any combination of direct measurement and estimation (as indicated by the solid diagonal line in the figure). Analyses relying solely on data collection would fall at the top right of the square, whereas analyses relying entirely on estimation are located at the bottom left of the square. The unique combination of data collection and estimation used for an analysis depends upon the needs and constraints of the analysis, analysis budget, available personnel and tools, and other constraints.

The information in this handbook concentrates on the collection or direct measurement of travel times (Chapter 6 contains several travel time estimation methods). Transportation analysts should be careful to recognize and treat accordingly the source of the data in the analysis and decision-making process.

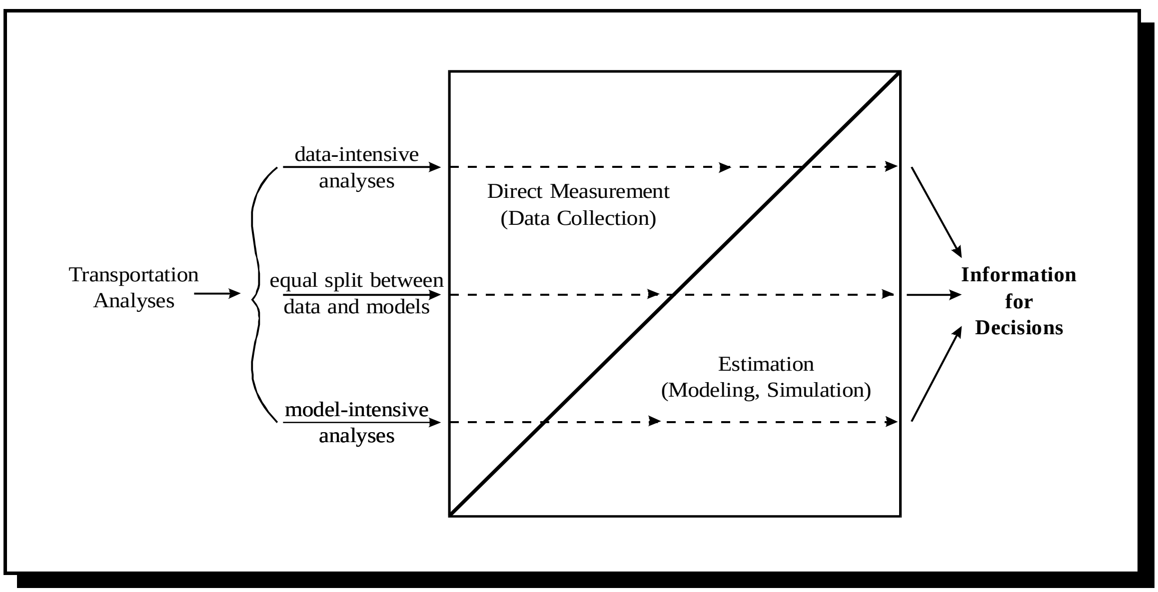


Figure 1-2. Relationship Between Direct Measurement and Estimation Techniques in Transportation Analyses

1.7 References for Chapter 1

1. Berry, D.S. and F.H. Green. "Techniques for Measuring Over-All Speeds in Urban Areas." In *Proceedings*. Highway Research Board, National Research Council, Volume 28, 1949, pp. 311-318.

2. Berry, D.S. "Evaluation of Techniques for Determining Over-All Travel Time." In *Proceedings*. Highway Research Board, National Research Council, Volume 31, 1952, pp. 429-439.

3. *Better Transportation For Your City: A Guide for the Factual Development of Urban Transportation Plans*. Procedural Manual 3B, National Committee on Urban Transportation, Public Administration Service, Chicago, Illinois, 1958.

4. *Manual of Transportation Engineering Studies*. Robertson, H.D., editor, Institute of Transportation Engineers, Washington, DC, 1994.

5. *Highway Capacity Manual: Special Report 209*. Transportation Research Board, Washington, DC, 1994.

6. Lomax, T., S. Turner, G. Shunk, H.S. Levinson, R.H. Pratt, P.N. Bay, and G.B. Douglas. *Quantifying Congestion: User's Guide*. NCHRP Report 398. Transportation Research Board, Washington, DC, November 1997.

7. McShane, W.R. and R.P. Roess. *Traffic Engineering*. Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1990.

8. Wardrop, J.G. "Some Theoretical Aspects of Road Traffic Research." In *Proceedings Institute of Civil Engineers*. Road Engineering Division Meeting, London, Great Britain, January 1952, pp. 325-362.

9. Dowling, R., W. Kittelson, A. Skabardonis, and J. Zegeer. *Planning Techniques to Estimate Speeds and Service Volumes*. NCHRP Report 387. Transportation Research Board, Washington, DC, September 1996.

10. May, A.D. *Traffic Flow Fundamentals*. Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1990.