CHAPTER 8

Traffic Data Collection and Reduction Methodologies

The starting point for most traffic engineering is a comprehensive description of the current state of the streets and highways that comprise the system, current traffic demands on these facilities, and a projection of future demands.

This requires that information and data that can quantitatively describe the system and its demands be assembled. As the highway system is massive, and demands are both time- and location-sensitive, assembling this information is a massive task. Nevertheless, data must be collected and reduced to some easily interpreted form for analysis.

Collection and reduction of traffic data covers a wide range of techniques and technologies from simple manual techniques (often aided by a variety of handheld or other devices for recording the data) to complex use of the ever-expanding technology of sensors, detectors, transmission, and computer equipment.

This chapter provides a basic overview of data collection and reduction in traffic engineering. The technology applied, as noted, changes rapidly, and traffic engineers need to maintain current knowledge of this field.

8.1 Applications of Traffic Data

The fundamental difficulty in traffic data collection and reduction is the need to observe and quantify the behavior of road users in real time over a large system. Consider the "simple" problem of observing traffic volumes in the midtown Manhattan street network—approximately from 14th Street to 59th Street, and from 1st Avenue to 12th Avenue. Such a network includes over 500 links that ideally would be observed simultaneously for perhaps a full day, or even several. No traffic agency would have access to sufficient equipment and/or personnel to do this successfully. Yet, for any traffic engineering to be done within this network, such information is absolutely necessary.

Traffic engineers collect and reduce data for many reasons and applications:

- *Managing the physical system.* The physical traffic system includes a number of elements that must be monitored, including the roadway itself, traffic control devices, detectors and sensors, and light fixtures. Physical inventories must be maintained simply to know what is "out there." Bulbs in traffic signals and lighting fixtures must not be burned out, traffic markings must be clearly legible, signs must be clean and visible, and so forth. Replacement and maintenance programs must be in place to ensure that all elements are in place, properly deployed, and safe.

- *Establishing time trends.* Traffic engineers need trend data to help identify future transportation needs. Traffic volume trends can identify areas and specific locations that can be expected to congest in the future. Accident data and statistics over time can identify core safety problems and site-specific situations that must be addressed and mitigated. Trend data allows the traffic engineer to anticipate problems and solve them *before* they actually occur.
- *Understanding travel behavior.* A good traffic engineer must understand how and why people (and goods) travel in order to provide an effective transportation system. Studies of how travelers make modal choices, trip time decisions, and destination choices are critical to understanding the nature of traffic demand. Studies of parking and goods delivery characteristics provide information that allows efficient facilities to be provided for these activities.
- *Calibrating basic relationships or parameters.* Fundamental characteristics such as perception-reaetion time, discharge headways at signalized intersections, headway and spacing relationships on freeways and other uninterrupted flow facilities, gap acceptance characteristics, and others must be properly quantified and calibrated to existing conditions. Such measures are incorporated into a variety of predictive and assessment models on which a great deal of traffic engineering is based.
- *Assessing the effectiveness of improvements.* When traffic improvements of any kind are implemented, follow-up studies are needed to confirm their effectiveness and to allow for adjustments if all objectives are not met.
- *Assessing potential impacts.* An essential part of traffic engineering is the ability to predict and analyze the traffic impacts of new developments and to provide traffic input into air pollution models.
- *Evaluating facility or system performance.* All traffic facilities and systems must be periodically studied to determine whether they are delivering the intended quantity and quality of access and/or mobility service to the public.

Data and information from traffic studies provide the underpinning for all traffic planning, design, and analysis. If the data are not correct and valid, then any traffic engineering based on the data must be flawed. Some of the tasks involved in data collection and reduction are mundane. Data and information, however, are the foundation of traffic engineering. Without a good foundation, the structure will surely fall.

8.2 Types of Studies

It would be literally impossible to list all of the studies in which traffic engineers get involved. Eleven of the most common types of studies include:

1. *Volume studies.* Traffic counts are the most basic of studies and the primary measure of demand; virtually all aspects of traffic engineering require demand volume as an input, including planning, design, traffic control, traffic operations, detailed signal timing, and others.
2. *Speed studies.* Speed characteristics are strongly related to safety concerns and are needed to assess the viability of existing speed regulations and/or to set new ones on a rational basis.
3. *Travel time studies.* Travel times along sections of roadways constitute a major measure of quality of service to motorists and passengers, and also of relative congestion along the section. Many demand-forecasting models also require good and accurate travel time measures.
4. *Delay studies.* Delay is a term that has many meanings, as we discuss in later chapters. In essence, it is the part or parts of travel time that users find particularly annoying, such as stopping at a traffic signal or because of a midblock obstruction.
5. *Density studies.* Density is rarely directly observed. Some modern detectors can measure "occupancy," which is directly related to density. Density is a major parameter describing quality of operations on uninterrupted flow facilities.
6. *Accident studies.* Because traffic safety is the primary responsibility of the traffic engineer, the focused study of accident characteristics, in terms of systemwide rates, relationships to causal factors, and at specific locations, is a critically important function.

7. *Parking studies.* These involve inventories of parking supply and a variety of counting methodologies to determine accumulations and total parking demand. Interview studies also involve attitudinal factors to determine how and when parking facilities are used.
8. *Goods movement and transit studies.* Inventories of existing truck-loading facilities and transit systems are important descriptors of the transportation system. Because these elements can be significant causes of congestion, proper planning and operational policies are a significant need.
9. *Pedestrian studies.* Pedestrians are an important part of the demand on transportation systems. Their characteristics in using crosswalks at signalized and unsignalized intersections and midblock locations constitute a required input to many analyses. Interview techniques can be used to assess behavioral patterns and to obtain more detailed information.
10. *Calibration studies.* Traffic engineering uses a variety of basic and not-so-basic models and relationships to describe and analyze traffic. Studies are needed to calibrate key values in models to ensure that they are reasonably representative of the conditions they claim to replicate.
11. *Observation studies.* Studies on the effectiveness of various traffic control devices are needed to assess how well controls have been designed and implemented. Observance rates are critical inputs to the evaluation of control measures.

This text includes a detailed treatment of volume studies, speed studies, travel time studies, delay studies, accident studies, and parking studies. Others are noted in passing, but the engineer is encouraged to consult other sources for detailed descriptions of study procedures and methodologies [*1*,*2*].

8.3 Data Collection Methodologies

In general, data collection takes place at one of three levels:

- Manual studies
- Semiautomated studies
- Fully automated studies

Despite all of the modern technology available to the traffic engineer, some studies are best conducted manually. These studies tend to be for short duration and/or at highly focused locations. The use of automated equipment requires set-up and take-down effort that may not be practical for a one-hour study, for example. Certain types of information are difficult to obtain without manual observation. Turning movements at an intersection are difficult to track without direct manual observation. Vehicle occupancy, frequently of interest, cannot be determined automatically with existing technology. Although the size of vehicles can be used to automate the determination of vehicle class (truck, bus, car), it cannot discern the difference between a private automobile and a taxi. Manual observations can be supported by a variety of handheld devices that assist in the recording of data or can be fully manual using paper forms to record data.

Semiautomated methods rely primarily on the use of pneumatic road tubes and a wide variety of recording devices that can be connected to such tubes. The primary characteristic of a semiautomated study is that the devices used are generally portable—that is, they can be moved from location to location. Other portable devices can also be used.

Fully automated studies rely on a wide variety of permanently installed detectors or sensors, usually in conjunction with connections to a stationary or portable computer station. The growth of sensor technology is ever-accelerating, and the state of the art in this area is a moving target. The same permanent detectors and sensors that can be used to collect traffic data of various sorts are also used to operate actuated and/or adaptive signals. The number of locations that have permanent detectors or sensors is rapidly increasing.

As is the case with satellite data, detection is no longer the restricting element in obtaining traffic data. The principal problem is that the electronic storage and filing capability of traffic agencies is significantly behind the sensor technology. Modern freeways are frequently monitored by large numbers of permanent detectors placed in the pavement or above it. The data at most detector locations, however, are only available in real time or in limited hourly summaries. Capturing and using detailed data often requires that a portable computer system be physically connected to the sensors to download data for storage in real time.

8.3.1 Manual Data Collection Techniques

As we have noted, short time frames, short lead times, and the need for certain types of data lead to manual data collection approaches. The types of studies most often conducted manually are (1) traffic counts at a specific location or small number of such locations, usually when the time frame is less than 24 hours, (2) speed or travel time data at a focused location for short duration, (3) observance studies at specific locations for short durations, and (4) intersection delay studies of short duration.

Traffic Counting Applications

The most likely situation leading to a manual study is the traffic count. A traffic engineer is often faced with a problem requiring some detailed knowledge of existing traffic volumes, which are generally needed quickly. A signal timing problem requires peak hour flow rates for the intersection, perhaps in the AM peak, the PM peak, and midday. Sending a few people out immediately to conduct such a study can produce the required data within a day.

Manual counts can be greatly facilitated through the use of push-button counters, such as those illustrated in Figure 8.1.

Hand counters have between four and six individual registers. On a single counter, an observer can keep track of up to four separate items. This allows an observer to classify volumes by vehicle type, turning movement, and/or vehicle type. When four are placed on a board, a professional traffic observer can keep track of these things for four legs of an intersection or different lanes on a freeway.

The primary difficulty with hand counters is that the data must be manually recorded in the field at periodic intervals. This disrupts the count. Obviously, while the observer writes down the register counts and resets them for the next period, vehicles are passing by uncounted. To obtain continuous count information on a common basis, short breaks are introduced into the counting procedure. Such breaks must be systematic and uniform for all observers. The system revolves around the *counting period* for the study—the unit of time for which volumes are to be observed and recorded. Common counting periods are 5 minutes, 15 minutes, and 60 minutes, although other times can be, and occasionally must be, used.

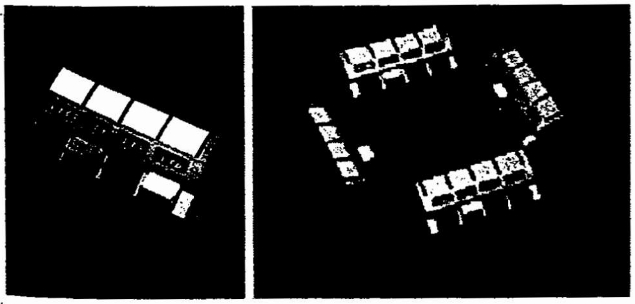


Figure 8.1: Hand Counters Illustrated

(*Source:* Used with permission of the Denominator Company.)

The short breaks are generally arranged in one of two ways:

- A portion of each counting period is set aside for a short break.
- Every other counting period is used as a short break.

In the first option, "x" out of every "y" minutes is counted. Thus, for 5-minute counting periods, an observer might count 4 of every 5 minutes; for a 15-minute counting period, 12 or 13 minutes of 15 minutes might be counted. To provide for a continuous count profile, the volume that is expected to occur during the short breaks must be estimated and added. This is simply done by assuming that the *rate of flow* during the missing minutes is the same as that during the actual count. Then:

$$V_y = V_x(x/y) \tag{8-1}$$

where: V_y = volume for continuous counting period of "y" minutes (vehs)
V_x = volume for discontinuous counts of "x" minutes (veh)
$y-x$ = short break time (minutes)
y = counting period (minutes)
x = counting period minus short break (minutes)

Consider a case where a manual counting survey is conducted by counting vehicles in 4 of every 5-minute period. If a count of 100 vehicles is obtained, what is the estimated count for the full 5-minute counting period? Using Equation 8-1:

$$V_5 = 100(5/4) = 125 \text{vehs.}$$

Although not necessary in this case, volumes are always reported as *full vehicles.* No fractions are permitted.

When alternating periods are used as breaks, full period counts are available in alternate counting periods. Missing counts are estimated using straight-line interpolation:

$$V_i = \frac{V_{i-1} + V_{i+1}}{2} \tag{8-2}$$

where: V_i = volume in missing counting period "i" (vehs)
V_{i-1} = volume in counting period "i−1" (vehs)
V_{i+1} = volume in counting period "i+1" (vehs)

Again, any estimated counts are rounded to the nearest whole vehicle.

Table 8.1: Data from an Illustrative Volume Study

		Actual Counts (4 minutes) vehs		Expanded Counts (x 5/4) vehs		Estimated Counts[1] vehs		Estimated Flow Rates veh/h	
Period	**Time (PM)**	**Lane 1**	**Lane 2**	**Lane 1**	**Lane 2**	**Lane 1**	**Lane 2**	**Lane 1**	**Lane 2**
1	5:00	24		30.0		30	*43*	360	516
2	5:05		36		45.0	*33*	35	396	540
3	5:10	28		35.0		35	*37*	420	564
4	5:15		39		48.8	*36*	49	432	588
5	5:20	30		37.5		38	*54*	456	648
6	5:25		47		58.8	*41*	59	492	708
7	5:30	36		45.0		45	*61*	540	732
8	5:35		50		62.5	*44*	63	528	756
9	5:40	34		42.5		43	*61*	516	732
10	5:45		48		60.0	*46*	60	552	720
11	5:50	40		50.0		50	*59*	600	708
12	5:55		46		57.5	*55*	58	660	696
Total		**192**	**266**	**240.0**	**332.6**	**496**	**659**		
% in Lane		41.9%	58.1%	41.9%	58.1%	42.9%	57.1%		

Italics indicate an interpolated or extrapolated value.

In practice, it is often necessary to combine the two approaches. Consider the example shown in Table 8.1. In this case, a single observer is used to count two lanes of traffic on an urban arterial. Using hand counters, the observer alternates between lanes in each counting period. Thus, for each lane, alternating counts are obtained. Because the observer must also take short breaks to record data, only 4 minutes of every 5 minutes are actually counted. Table 8.1 illustrates the three computations that would be involved in this study.

Actual counts are shown, and represent 4-minute observations. These are expanded by a factor of 5/4 (Equation 8-1) to estimate volume in continuous 5-minute counting periods. At this point, each lane has counts for alternating counting periods. Missing counts are then interpolated (Equation 8-2) to estimate the count in each missing period. The first period for lane 2 and the last period for lane 1 cannot be interpolated because they constitute the first and last periods. The counts in these periods must be extrapolated, which is at best an approximate process. All results are rounded to whole vehicles but only in the final step. Thus the "expanded counts" carry a decimal; the rounding is done with the "estimated counts," which include the expansion, interpolation, and extrapolation needed to complete the table. The "estimated counts" constitute 5-minute periods. The flow rate in each 5-minute period is computed by multiplying each count by 12 (twelve 5-minute periods in an hour).

Speed Study Applications

In Chapter 10, the analysis of speed data is fully discussed. Because of the statistical analysis of such data, sample sizes for most speed studies are generally in the range of 100 to 200. Unless there is permanent detection equipment at the desired study location, many speed studies are conducted manually by one of two methods:

- Measurement of elapsed time over a short measured highway segment using a simple stopwatch.
- Direct measurement of speeds using either handheld or fixed-mounted radar meters.

When using a stopwatch to time vehicles as they traverse a short section of highway (often referred to as the "trap"), there are two significant sources of error:

- Parallax (viewing angle)
- Manual operation of the stopwatch

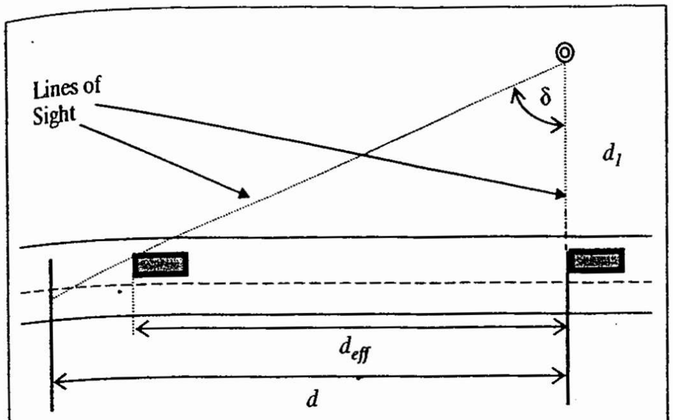


Figure 8.2: Parallax Error Illustrated

Parallax error is systematic, and adjustments can remove its impact, as long as the viewing angle is known. Manual operation of the stopwatch produces random errors that can either overstate or understate the measured travel time. If the trap is long enough, and the sample size is in the usual range, this error should average out.

Figure 8.2 illustrates the parallax error. Normally, an observer would choose a location at which one boundary can be viewed exactly. Because of the angle of vision of the other boundary, the observer actually "sees" the vehicle cross the boundary before it actually does. The observer thinks that travel times over distance d are being measured, whereas the travel times actually represent distance d_{eff}.

If angle δ is known, the correct speed can be computed. Based on trigonometry, the distance d_{eff} can be computed as:

$$d_{eff} = d_l Tan(\delta)$$

Then:

$$S_i = \frac{d_{eff}}{t_i} = \frac{d_l Tan(\delta)}{t_i} \quad (8\text{-}3)$$

where: S_i = speed of vehicle "i" (ft/s)

d_{eff} = effective distance over which the travel time of vehicle "i" is measured (ft)

t_i = travel time for vehicle "i" to traverse the effective distance (s)

d_l = perpendicular distance of observer from line of travel (ft)

δ = angle between lines of sight (degrees).

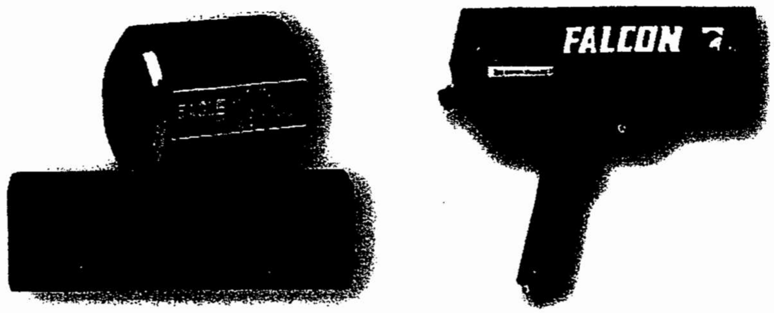
The random error due to manually starting and stopping the stopwatch is more difficult. Assume that an average observer may have an error of ± 0.20 s each time the stopwatch is started or stopped. Thus, for a given observation, and error as large as ± 0.40 seconds is possible. If the combination of observed speed and length of trap produced travel times in the range of 1.0 seconds, the error could be as large as 40%. If a longer trap is used, and the average travel time increases to, for example, 4.0 seconds, the potential error is reduced to 10%. The trick is to find an appropriate trap length that minimizes the random stopwatch error but that can still be effectively observed. If the average speed on a particular highway were thought to be in the 50 mi/h range, and average travel times around 4.0 seconds were desired, the trap length would have to be 1.47*50*4.0 = 294 ft, which is certainly easily "observable."

Use of radar meters for speed measurement is the most common method to obtain speed data. Unfortunately, this method of measuring speeds is also associated with enforcement of speed laws. Thus, once the observation station is identified by drivers, everyone slows down, and the results do not reflect ambient driver behavior. Therefore, concealment of the device and the personnel involved in the study is important. Because such meters require a clear line of sight of oncoming vehicles, such concealment is often difficult to accomplish for a significant length of time. Figure 8.3 illustrates common types of radar meters used to collect speed data.

Radar meters use the Doppler principle to measure speeds. A radar wave is reflected from a moving object (vehicle) and returns at a different frequency. The difference in emitted and reflected frequency is proportional to speed. Exact measurements require that the wave be in line with the approaching vehicle. Any angle creates a systematic error, much in the same way as parallax affects manual observations. Because most radar measurements must be made from a roadside or overhead location, there is virtually always an angle involved. Most meters, however, have an adjustment that can be entered based on the angle of deflection of the wave; results are automatically implemented and the correct speed is read directly.

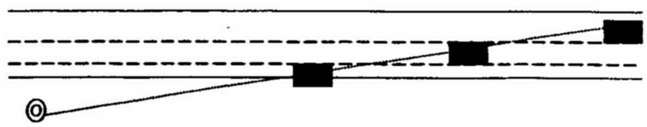
As illustrated in Figure 8.3 (c), using radar meters on multilane highways creates some interesting problems. Given a shallow angle (desirable for accuracy), the emitted wave may reflect off a vehicle in lane 1, 2, or 3. As shown in Figure 8.3 (c), the longitudinal location of the vehicle when the wave is reflected can vary greatly depending on what lane the vehicle is in. This sometimes makes it difficult to identify *which vehicle* has been observed.

Because radar meters emit waves within the federally regulated range of frequencies, each radar meter must have a license from the Federal Communications Commission (FCC). Most radar meters are accurate to ± 2 mi/h and should not be used where great precision and accuracy is needed.



(a) Vehicle-Mounted Radar Unit
(Photo courtesy of Tribar Industries)

(b) Hand-Held Radar Unit
(Photo courtesy of Tribar Industries)



(c) Resolving Multilane Traffic Streams with Radar

Figure 8.3: Measuring Speeds with Radar Meters

Manual speed studies are particularly interesting because it is necessary to obtain a strictly random sample. Even the most experienced observer cannot measure the speed of *all* vehicles passing a point. Therefore, some common problems must be avoided: (1) avoid trying to measure the "fastest" and/or "slowest" vehicles, (2) where platooning of vehicles exist, remember that only the first driver in the platoon is actually choosing his or her speed; (3) truck or other heavy vehicles speeds should not be specifically targeted unless the study is focused on truck speeds. Although it may seem contradictory, assuring a random sample generally requires a very rigid sampling process, such as "every third vehicle in each lane."

Other Manual Study Applications

Although vehicle counts and simple speed studies are the most often conducted using manual observations and recording of data, there are others, some of which are discussed in Chapter 9 and 10 in greater detail:

- *Intersection delay studies:* These are most often done by hand, given that they tend to focus on short-term peaks in demand.
- *Travel time studies:* These most often involve test vehicles moving within the traffic stream, with data observers/recorders marking appropriate times that various landmarks or other known locations are passed.
- *Observance studies:* These usually involve short-term observations of how well drivers are obeying a given regulation or control device; very common at STOP-controlled intersections.
- *Parking and parking inventory studies:* These often involve manual observation of parking supply and accumulation.

Personnel Considerations

Manual studies must be adequately staffed. From a simple intersection count, which might involve four to six people, to complex network studies involving hundreds of people. staffing and training are always important components of manual studies.

For larger studies, it is virtually impossible to assemble a working group consisting of only experienced traffic personnel. The most common approaches are to hire students from nearby college campuses and/or use of temporary agencies. In either case, it is critical that all personnel be carefully trained to understand the importance of their tasks and exactly what is expected of them. Predesigned field sheets should be available to avoid mistakes and should be carefully presented to all personnel. Such issues as communications among field personnel, use of any equipment, and how and where to provide results at the end of data collection must also be carefully planned.

For multiple counts, a real-time communication system is needed that connects all observers to a supervisor. Counts in such situations must all start and stop at exactly the same time; a single supervisor times the study and issues "start" and "stop" orders as appropriate.

For studies longer than 1 or 2 hours, sufficient personnel must be trained to allow for periodic relief of observers. There will always be "no shows" for any large study, so "extra" personnel is also needed to cover these eventualities. Practical limitations must also be recognized: A typical worker not experienced in traffic studies, for example, could be relied on to count and classify one heavy or two light movements, or to measure speeds in one lane.

8.3.2 Portable Traffic Data Equipment/Semiautomated Studies

A large number of traffic studies are conducted using a variety of portable traffic data collection/recording devices. The most common portable device used in traffic studies is the pneumatic road tube. A pneumatic road tube is a closed-end tube in which an air pressure is maintained. When stretched across a roadway, a vehicle (actually an axle) rolling over it creates an air pulse that travels through the tube, which is connected to some form of data capture device. Such tubes are most often used for traffic counting, but they can also be used to measure speed. Figure 8.4 shows a typical field setup using pneumatic road tubes.

Note that Figure 8.4 shows two road tubes attached to the counter. This is to provide backup in case one of the tubes breaks. Pairs of tubes can also be used to measure speed; the recording device measures the elapsed time between the actuation of the first and second tubes. This practice is rarely applied today because radar meters have become the dominant technology to measure speeds. It is, however, the origin of the colloquial term *speed trap*. Police (in the 1940s and 1950s) often used the dual tubes to measure speed; because the distance between them was always referred to as "the trap," the term is now in use for any location at which police enforce speed limits.

Figure 8.4: Road Tubes with Portable Counter Illustrated

Although a variety of traffic counters are available to use with road tubes, the most common types record a total count at preset intervals, so that 5-, 10-, 15-, and 60-minute counts can be automatically recorded.

The primary difficulty with road tubes is that they do not count vehicles—they count axles. A passenger car with two axles crosses the road tube registering a pulse *twice*. A tractor-trailer combination with multiple axles may cause as many as five or six actuations that will be recorded. To obtain an estimate of vehicle counts, manual observations must be made to determine the *average number of axles per vehicle*. Obviously, if this has to be observed for the entire period of the study, there is no point in using road tubes. Representative samples do, however, have to be collected. If a road-tube count is being taken over a week, for example, manual classification counts might be taken for 5 to 10 hours at representative times during the week (AM peak, PM peak, off-peak).

Table 8.2 illustrates a sample classification count. Vehicles are observed and classified by the number of axles on each. As shown, these data can be used to estimate the average number of axles on a vehicle at the study location.

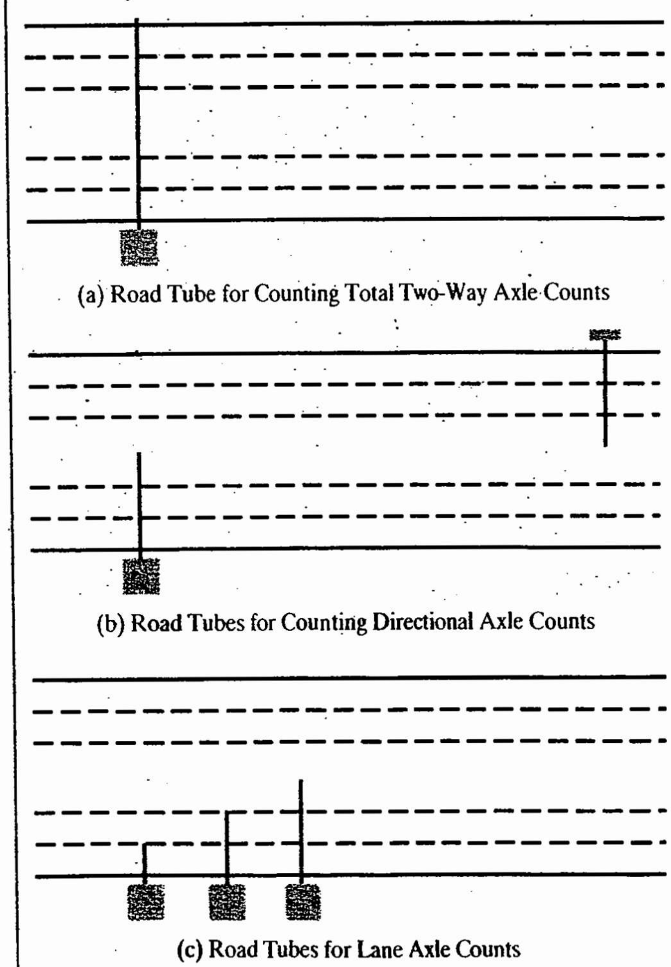
The average number of axles per vehicle at this study location is 1205/515 = 2.34 axles/vehicle. If the recording device shows a count of 7,000 axles for a given day, the estimated vehicle count would be 7,000/2.34 = 2,991 vehicles.

Table 8.2: Sample Classification Count for a Road-Tube Volume Study

Number of Axles	Number of Vehicles Observed	Total Axles for Observed Vehicles
2	400	× 2 = 800
3	75	× 3 = 225
4	25	× 4 = 100
5	10	× 5 = 50
6	5	× 6 = 30
Total	**515**	**1,205**

There are also a number of practical issues with road tubes:

- If not tautly fastened to the pavement (usually accomplished with clamps and epoxy), the road tube can start a "whipping" action when vehicles continually traverse it, causing an eventual breakage. Once broken, the tube cannot relay data. Road tubes are also subject to vandalism. In either event, the tube should be inspected at regular intervals to ensure that it is still functioning.
- If the road tube is stretched across more than one lane, simultaneous actuations are possible, and the recorded counts may low because of this. Obviously, this problem gets worse as the number of lanes and the volume of traffic increases.
- Traffic counters (recording devices) are also subject to vandalism and/or theft and must also be periodically checked to see that they are functioning.



(a) Road Tube for Counting Total Two-Way Axle Counts

(b) Road Tubes for Counting Directional Axle Counts

(c) Road Tubes for Lane Axle Counts

Figure 8.5: Alternative Field Setups for Road Tubes

Figure 8.5 illustrates common setups for road tubes as used in traffic-counting studies. Figure 8.5 (a) shows a single tube across all lanes of a facility. In this configuration, a total two-way count of axles is obtained. Figure 8.5 (b) shows the most common technique—two road tubes set up to record axles in each direction separately. Figure 8.5 (c) shows a less typical setup in which lane counts can be deduced. The tubes must be close enough together that the number of lane changes within the detection range is minimal.

Other types of portable detectors can be used. Portable plate detectors can be fastened to a specific lane. Using wave emissions, such detectors can measure volume, speed, and occupancy and send the data wirelessly to a roadside computer. They can also classify vehicle types by length. They tend to be expensive and can only monitor one lane at a time. Most studies would require several such detectors. An observer generally must be present to monitor the portable computer used to store the data and to ensure that the detectors are not stolen.

There are also devices that operate using electronic tape switches fastened to the pavement. These operate by interpreting current disruptions caused by vehicles crossing over the tape switch. A double wire is generally fastened to the pavement under a tough form of tape and is attached to a low-grade power source. When a vehicle crosses the tape switch, a surge of current occurs that can be monitored by a variety of portable recording devices.

8.3.3 Permanent Detectors

Rapid advances in traffic detector technology are rapidly changing the landscape for traffic studies. Detectors are used for all types of things, from data collection and transmission to the real-time operation of traffic signal systems. As intelligent transportation technology marches forward, there is great interest in real-time monitoring of traffic systems on a massive scale. This requires that the traffic system be instrumented with large numbers of permanent detectors and the capability to observe the data they provide in real time.

In the 1960s, very few permanent detectors were in place, and most were used to operate early versions of actuated signals. Today, thousands of permanent detectors are installed on freeways, at intersections, and other locations. These detectors provide the opportunity to gather large amounts of data on the traffic system. The difficulty is that much of the data is only available in real time—that is, it is not permanently stored in a retrievable form, and the variety of technologies in use makes it difficult to coordinate everything into a seamless system of critical information on the system.

The Traffic Detector Handbook [3] provides an excellent overview of current detector and sensor technology. It classifies detectors and sensors into a number of broad categories based on the type of technology used:

- Sound (acoustic)
- Opacity (optical, infrared, video image processing)
- Geomagnetism (magnetic sensors, magnetometers)
- Reflection of transmitted energy (infrared laser radar, ultrasonic, microwave radar)
- Electromagnetic induction (inductive loop detectors)
- Vibration (triboelectric, seismic, inertia switch sensors)

These technologies have advanced dramatically from the earliest detectors. The first widely used detectors were pressure plates. Two steel plates were separated by a rubber spring. The plates were connected to a low-voltage power source. When a vehicle (axle) crossed the pressure plate, the two plates came together, completing the circuit and creating an electrical pulse. Although technologically simple, there were many practical problems with pressure plates. Snow plows and other equipment could dislodge them; they invariably led to deterioration of the pavement around them; or water could get between the plates and freeze, providing a permanent current and rendering the device inoperable. There are still isolated locations where pressure plates are still in use, but none are being installed at this point.

The most prevalent detector in use today is the inductive loop. When a metal object (vehicle) enters the field of the loop detector, inductance properties of the loop are reduced and sensed, thus recording the presence of the vehicle. The loop essentially creates an electromagnetic field that is disturbed when a metal object enters it. Induction loops require that a cut be made in the pavement surface, with one or more wire loops placed in the cut. A pull wire connects the detector to a power source, which is then connected to a controller unit. Figure 8.6 shows a typical installation of an inductive loop.

The standard induction loop detector measures 6 ft × 6 ft and covers one lane. Multiple detectors are needed to monitor multiple lanes. Longer loops are available in sizes ranging from 6 ft × 40 ft to 6 ft × 80 ft. These are often used in conjunction with actuated signals requiring a significant detection area. In some cases, a long detection area is provided by installing a series of 6 ft × 6 ft detectors in each lane.

Inductive loop detectors directly measure the presence and passage of vehicles. Other important measures, such as speed and density, can be deduced using calibrated algorithms, but the accuracy of these is often insufficient for research use.

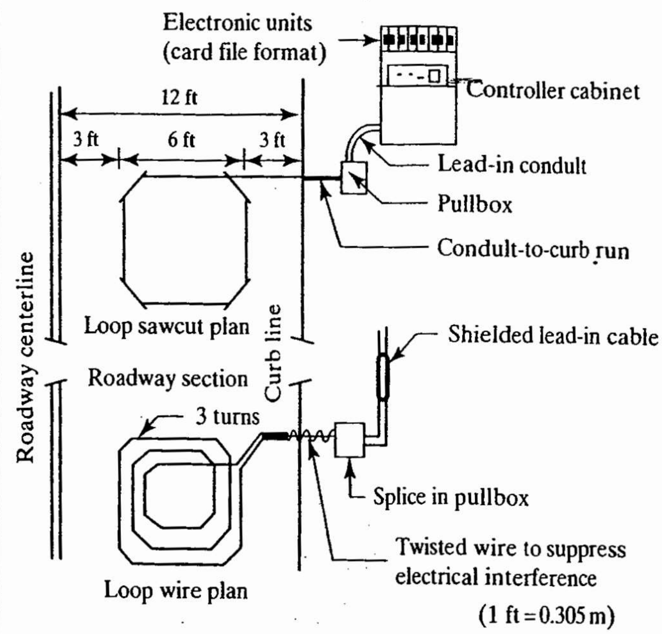


Figure 8.6: Typical Installation of an Induction Loop Detector

(*Source: Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-4, pp. 1–12.)

Magnetic detectors come in two forms: the magnetometer and magnetic sensors. Because of the details of their design, the magnetometer can detect both passage and presence, whereas magnetic sensors detect only passage. Both operate on the principle that a moving metal object (vehicle) disturbs the earth's ambient magnetic field and that the disturbance can be monitored and counted. The magnetometer also has a second wire loop that operates on a basis similar to the inductive loop to detect presence. Both types of detectors are placed *under* the roadway on a structure or in the subbase. As a passage-only detector, magnetic sensors have limited applications.

A variety of permanent detectors use the same Doppler principle as handheld radar meters. They all rely on reflected energy from vehicles that can be detected and used to obtain a variety of traffic parameters. These include microwave radar meters, infrared sensors, laser radar meters, and ultrasonic detectors. The difference lies in the wavelength and frequency of energy that is emitted and sensed.

Figure 8.7 illustrates an overhead installation of a microwave radar detector. In this configuration, the detector monitors a single lane or two lanes. Figure 8.8 illustrates an alternative application in which the detector is located at the roadside and covers all lanes of an approach. The illustration

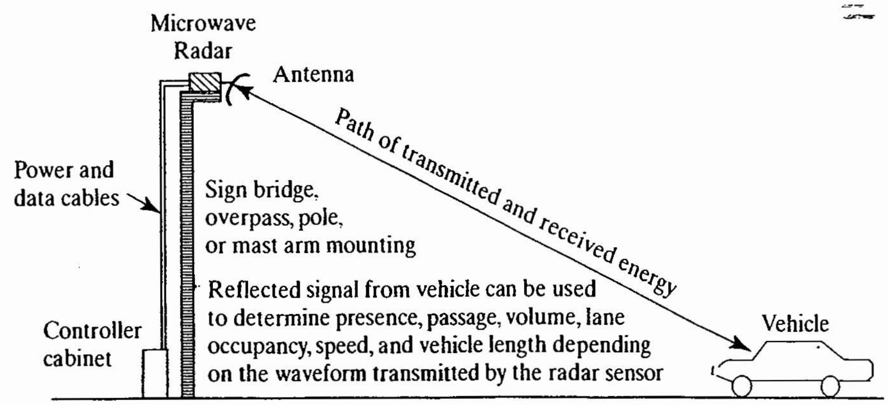


Figure 8.7: Overhead Installation of a Permanent Microwave Radar Detector

(*Source: Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-7, p. 1-16.)

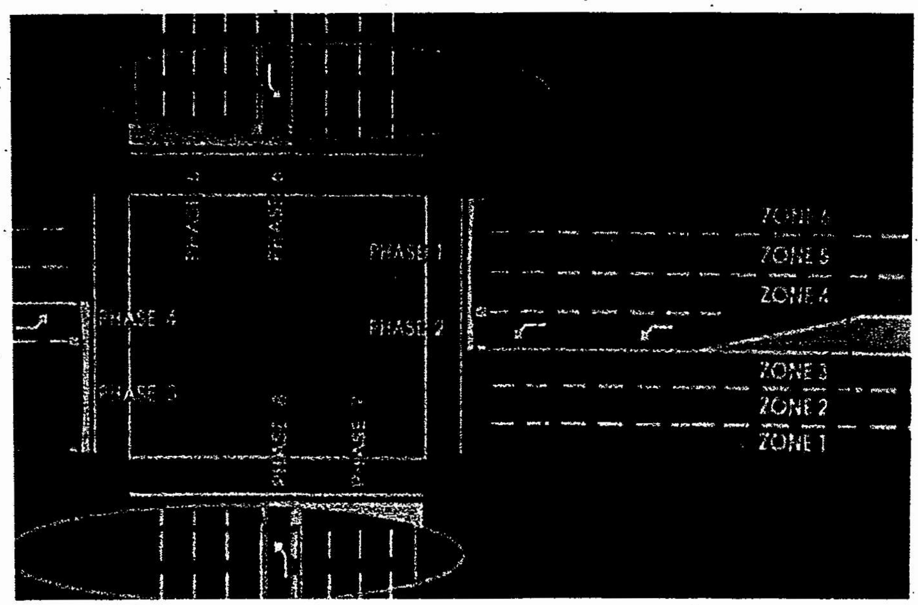


Figure 8.8: Roadside Installation of Permanent Microwave Radar Detectors

(*Source: Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-8, p. 1-17.)

of Figure 8.8 is at a signalized intersection, and the detectors are being used to operate an actuated signal.

Figure 8.9 shows an overhead installation of a laser infrared radar detector. Using two beams, it can actually create an image of vehicles within its range, allowing for automated vehicle classifications.

Perhaps the most exciting recent development in real-time traffic detection is the rapid advancement of video image processing (VIP) technologies. Cameras are installed (digital video) typically on a mast arm, often at a signalized intersection location. The camera can be focused on a single lane but can also be used to monitor multiple lanes. The system consists of the camera, a microprocessor to store and interpret images, and software that converts the images to traffic data. In essence, vehicles appear on a video image as a compressed package of pixels moving across the image. The system is calibrated to recognize

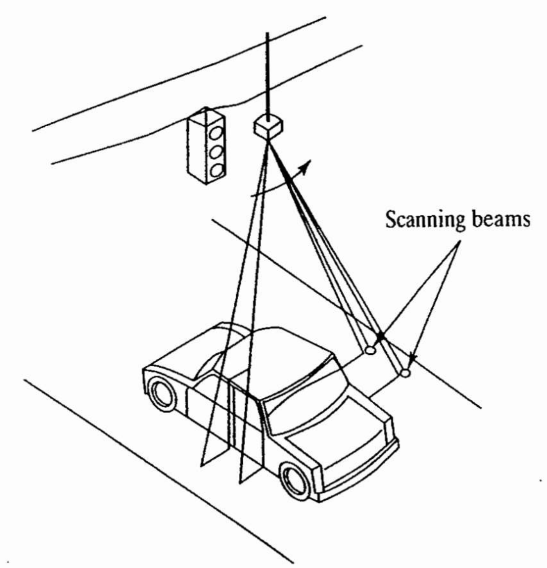


Figure 8.9: An Overhead Laser Infrared Radar Installation

(*Source: Traffic Detector Handbook*, 3rd Edition, Federal Highway Administration, Publication No. FHWA-HRT-06-108, Washington DC, 2006, Figure 1-9, p. 1-18.)

the background image and account for changes due to ambient and artificial light and weather. Available software can discern and classify vehicles by length, count by lane, and provide speeds. VIPs are now being used to operate actuated signals in some locations, and it is almost certain that this technology will advance rapidly over the near and moderate term future.

8.4 Data Reduction

The process of data reduction is critical to the accuracy of any study. The process varies widely depending on the manner in which data is collected, but essentially it involves taking data in whatever raw form it is observed and "reducing" it to some understandable form.

In manual studies, this most often involves taking handwritten forms from various observers at one or more locations and organizing it into a recognizable form. It may involve expansions, interpolations, and extrapolations as discussed previously. It always involves presenting data in a format that allows for efficient and effective analysis.

In the simple case, for example, of a manual count at an intersection, the data would be assembled from the four to six observers involved and entered into tables such that volumes or flow rates of all movements can be discerned for common time intervals. Table 8.3 shows a common format used to depict intersection volumes and/or flow rates.

The tabulated data allows the analyst to see the pattern of volume over time on a movement-by-movement basis. When the data are collected using portable or permanent automated equipment, the data can be placed directly into a spreadsheet for subsequent analysis. Spreadsheet data can also be used to create useful graphs and other visual depictions to further clarify the meaning of the data.

Where data is collected by permanent detectors, it can be sent directly (either through wired or wireless technologies) to centralized computers into a predesigned databank, where standard tabular and graphic displays can be created. As previously discussed, however, data collection technology has advanced far faster than the technology for creating organized databases into which *all* data is entered, and from which *all* data can be conveniently retrieved. Most data that are observed exist only in real time. Portable devices can be connected to a variety of detector inputs, from road tubes to induction loops, to extract data over some period of time for permanent storage.

8.5 Cell Phones

Technology exists that can track the location of cell phones (as long as they are turned on) to reasonably small areas. It is possible, therefore, to use this technology to track vehicles in time and space, yielding data that would be hard to obtain by other means, such as origin destination and routing information. Such use, however, raises a number of issues concerning the rights of privacy and the extent to which people are willing to accept a "big brother" watching our activities. Technology now provides a plethora of ways in which people can be observed without being aware of it. Such technologies are already in use for law enforcement purposes, but they have also been subject to legal challenges. This technology will continue to develop rapidly; its usefulness as a means of collecting useful transportation data will be subject to legal restrictions as determined by the courts and legislatures over time.

8.6 Aerial Photography and Digitizing Technology

As the state of the art moves more toward the need to observe, interpret, and manage system behavior, the approaches to data collection and reduction must change as well. Historically, traffic data collection focused on isolated locations or a limited number of isolated locations. Today, the ability to provide

Table 8.3: Sample Intersection Count Table

	Eastbound				Westbound				Northbound				Southbound			
Time Period	**L**	**TH**	**R**	**Tot**	**L**	**TH**	**R**	**Tot**	**L**	**TH**	**R**	**Tot**	**L**	**TH**	**R**	**Tot**
1																
2																
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individual drivers with real-time traffic and routing information is rapidly advancing. Navigation systems, available on only a few very expensive vehicles a decade ago, can now be purchased for any vehicle at an increasingly reasonable cost. The problems of urban congestion make it increasingly important to understand the state of the overall transportation system and the way in which individuals use it.

The rapid development of detector technology now allows engineers to place large numbers of devices throughout the highway system. The ability to synthesize all of this information into a usable real-time resource is also rapidly developing.

Existing technologies, however, do allow researchers to look at larger parts of the highway system through the use of aerial photography. Some of this technology has been around for a long time. In the late 1960s and early 1970s, time-lapse photography from fixed wing aircraft or helicopters was used to trace vehicles through long segments of highways. The state of the art of film technology at that time limited the photography to one or two frames per second, and it allowed only a few hours of data to be observed during one flight. Modern digital technology allows for continuous photography over longer periods of time. Some current systems can now resolve vehicle locations as many as 16 times each second. Eventually, the use of satellites will become common. Even today, sections of highway can be examined using satellite images available through the Internet. This greatly simplifies the process of examining the geometric characteristics of sites and the selection of individual sites for study. The technology does not, however, provide sufficient time-sequenced images to be used directly for data collection.

Aerial photography is now being used to observe moderately sized highway segments as opposed to individual locations. This technology is useful for studying weaving sections, interchanges, arterial sections, a series of intersections, and similar locations. Because aerial photography can capture an entire segment in the photographic field, it allows individual vehicles to be traced as they traverse the segment. Thus such information as lane changes, queue formation and dissipation, local origin and destination, and similar data can be retrieved, in addition to the more standard counts, vehicle classifications, and speeds.

"Aerial" photography uses three basic platforms: (1) a stationary elevated vantage point, where available (such as a tall building), (2) helicopters, and (3) fixed-wing aircraft. Where available, elevated vantage points are highly desirable because the camera frame remains fixed throughout the study. They are difficult to find, however, and must be within a reasonably short distance from the site to provide a favorable view of the study segment. Helicopters have the ability to hover over a single location but cannot do so for long periods

Figure 8.10: Aerial Photograph of a Freeway Interchange

of time; even when "hovering," the aircraft rotates so that the photographic image does not remain fixed. Fixed-wing aircraft can stay over a given site for longer periods of time, but they do not remain in a fixed location; they fly back and forth in a pattern that keeps a designated highway segment in the image range. The orientation of the photography, however, is constantly changing. Figure 8.10 illustrates an aerial photograph of a freeway interchange taken from a fixed-wing aircraft. The same type of image could have been obtained from a helicopter or a fixed elevated vantage point—although the latter would not be right overhead but at an angle from the fixed vantage point.

A process called "digitizing" captures individual vehicle traces through the photographed segment. This requires that two or more fixed objects with known coordinates be within every frame to be captured. As noted previously, some systems capture a frame up to 16 times per second, although as few a 2 to 4 times per second can also produce reasonable data. Each frame is shown on a large screen. An observer fixes cross hairs over each of the fixed objects with known coordinates; this establishes a grid coordinate system for the frame. The cross hairs are then placed over each vehicle (a fixed position, such as the front left corner of the vehicle is chosen), and the coordinates are automatically entered into a computer. This process is completed for each vehicle in each frame. Even though the process is "automated," it still is labor intensive. When all coordinates for all vehicles in all frames are entered, software analyzes the data and links vehicles in successive frames by assigning probabilities of a match based on logical paths. Where the software does not provide a match from frame to frame, the operator must go back to the frames and manually make the link by identifying the vehicle match from frame to frame. Current technologies can usually match about 50% of all vehicles automatically.

When the linkages are complete, the software produces detailed vehicle traces, showing position of the vehicle in each frame with the appropriate time stamp. Study-specific software is then written to extract the type of data needed for analysis. Position data from frame to frame can provide speed between frames, lane changes between frames, and other microscopic data that allows for very detailed analysis of the operation of the study segment.

Because this type of data collection and reduction is expensive, it is normally reserved for research applications. In a recent study of weaving segment operations [*4*], two hours of such data cost approximately $15,000, using a capture rate of two frames per second. A large quantity of such data is now being collected for the Next Generation Simulation Study (NGSIM) [*5*], using a capture rate of 16 frames per second. It seeks to provide a very detailed database for the development of a new generation of traffic simulation programs.

8.7 Interview Studies

Many types of information cannot be obtained except through direct interviews with travelers. This is particularly true where information on trip purpose and background information on travel choices is required.

8.7.1 Comprehensive Home Interview Studies

The largest scale interview studies involve comprehensive area-wide origin-destination studies, where the typical travel patterns of people within a broad study area are desired. Comprehensive home interviews are conducted in which information on all trips made by all household members the previous day is sought. Sampling is critical to such studies because the sampling rate is often quite low, depending on the size of the area. Setting up the study is complex and involves establishing origin and destination zones that are small enough to provide trip patterns but large enough to allow a reasonable number of interviews to be conducted within each. Appointments must be made for all interviews, and interviewers need formal identification to reassure the interviewees. Law enforcement must be notified of the activity, and any required permits must be acquired. Interviewers need to be well trained and articulate, and a dress code is normally recommended. Interviews are often done in the evening when the maximum number of household members are present. The interviewer extracts detailed information on all trips made the previous day, including time of start and finish, location of start and finish, trip purpose, mode or modes used, transfer locations, and route. Basic demographic information on each household member is also collected, including gender, age, occupation, driver's license status, and so forth. General household income and car ownership is also recorded, as is information on the type of housing.

Comprehensive home interview studies take place over a period of months, perhaps even years, and are very costly. When all data are collected, typical daily origin and destination patterns are created. The origin end is often treated as the "producer" of the trip and is (for about 85% of all trips) a residential location. The destination end is often treated as the "attractor" of the trip and generally involves a location related to the trip purpose (i.e., a place of employment, shopping, recreation, etc.). Models are then calibrated to predict the number of trip productions and attractions in each zone based on known census characteristics of the zone. These are referred to as "trip generation models." Other models are then calibrated to link trip origins to destinations and are referred to as "trip distribution models." "Modal split" models are then developed to predict how travelers will make choices on the transportation mode(s) to be used for each trip. Finally, "traffic assignment" models attempt to predict specific routes that will be used on a typical day. Such studies are normally conducted as part of periodic area-wide transportation planning projects, often in conjunction with a census.

8.7.2 Roadside Interview Studies

Some studies require that motorists be approached during a trip they are making. This is a tricky business because it causes disruption to individual drivers and can cause localized congestion, which annoys motorists. Such interviews need to be short and efficient, and they normally do not consist of more than five simple questions, usually involving such information as trip purpose, trip origin, trip destination, and route.

At locations where drivers will be stopped and interviewed, police security is virtually always required. A typical location might be a roadside location along a nonfreeway highway. Signing and traffic zones must be set up to adequately warn drivers that they may be pulled aside for a brief interview. Generally it is impossible to interview all vehicles passing a location, so police are used to "flag down" those that will be selected for interview. The interview in such cases should take no more than a minute to complete, to avoid undue disruption to individual drivers and to prevent long queues from forming at the interview site.

Drivers might also be stopped on entrance ramps to a freeway. At these locations, an attempt to interview all drivers is made, but each interview should be in the order of 15 seconds. Most often, because the entry point to the freeway is known, information on the destination exit, trip purpose, and trip frequency would be asked.

At signalized intersections, interviewers (multiple) can approach drivers stopped for a RED signal, and ask a series of short questions—which must be completed before the light turns GREEN.

A great deal of useful information can be amassed using roadside interview techniques. The studies must be conducted carefully, however, to avoid causing traffic jams, annoying drivers more than minimally, and to assure security for both motorists and interviewers.

8.7.3 Destination-Based Interview Studies

Another common interview technique is to focus on a known destination. In such cases, the trip destination is known, and interviewees need not be stopped while making their trip. Common locations include shopping centers, sports complexes, airports, beaches and other recreational facilities. Interview stations are established at key locations, and interviewees are asked to participate, as opposed to being obligated to participate by police. Questions on trip origin, route, mode choice (where such choice is available), trip purpose and frequency, and trip times are asked. Again, each interview should take no more than one or two minutes.

8.7.4 Statistical Issues

Chapter 7 addresses a number of statistical issues involved in interview studies, such as determination of sample size and expansion of interview data to reflect a full population.

8.8 Concluding Comments

This chapter attempts to provide a broad overview of the complex subject of data collection and reduction for traffic engineering studies. Subsequent chapters discuss specific types of studies in greater detail and present a more comprehensive picture of how specific types of data are analyzed and appropriate conclusions are drawn. The technology for collecting, storing and retrieval, and reduction of data continues to advance at a rapid pace, and you are encouraged to check the most current literature to get a more up-to-date view of the state of the art.

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4. Roess, R., "Analysis of Freeway Weaving Sections." *Final Report*, National Cooperative Highway Research Project 3-75, Polytechnic University, Brooklyn NY, January 2008.
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Problems

1. Traffic volumes on a four-lane freeway (two lanes in each direction) were counted manually from an overhead location, resulting in the data shown here. The desire was to obtain continuous 15-minute counts for each lane of the freeway for a two-hour period surrounding the morning peak hour.

Data for Problem 1

	Eastbound		Westbound	
Time of Count (PM)	Lane 1	Lane 2	Lane 1	Lane 2
4:00–4:12		360		310
4:15–4:27	350		285	
4:30–4:42		380		330
4:45–4:57	370		300	
5:00–5:12		370		340
5:15–5:27	345		280	
5:30–5:42		340		310
5:45–5:57	320		260	

From the data shown, determine the following:

(a) Continuous 15-minute volumes for each period and each lane.

(b) The peak hour, peak hour volume, and peak hour factor (PHF) for each direction of flow and for the freeway as a whole.

(c) Directional flow rates during each 15-minute count period.

2. A 24-hour count using a road tube at a rural highway location produces a count of 11,250 actuations. A representative sample count to classify vehicles resulted in the data shown here:

Data for Problem 2

Number of Axles Per Vehicle	Number Observed
2	157
3	55
4	50
5	33
6	8

Based on this sample classification count, how many vehicles were observed during the 24-hour study?

3. A speed study was conducted using manual observation with stopwatches. The trap length was marked for 400 feet. The observer lined up with the entry boundary line, 60 feet away from the vehicles being observed. When viewing the exit boundary, the sight line was at a 60° angle from a perpendicular line from the observer location to the entry boundary. If one of the observed travel times to traverse the trap is 8.3 seconds, at what speed is the vehicle traveling?

4. Briefly describe the types of permanent detectors available for use in traffic studies. Note the benefits and drawbacks of each.