CHAPTER 9

Volume Studies and Characteristics

The most fundamental measure in traffic engineering is volume: how many vehicles are passing defined locations in the roadway system over time, particularly during the peak hour(s) of a typical day. Virtually no decision concerning facility design or traffic control options can be made without knowledge of existing and projected traffic volumes for the location(s) under study.

9.1 Critical Parameters

In Chapter 5, we introduced the concepts of volume and flow rate. Four variables are related to volume:

- Volume
- Rate of flow
- Demand
- Capacity

Sometimes these are used in conjunction with other measures or conditions. The four parameters listed are closely related, and all are expressed in terms of the same or similar units. They are *not*, however, the same.

1. *Volume* is the number of vehicles (or persons) passing a point during a specified time period, which is usually one hour but need not be.
2. *Rate of flow* is the rate at which vehicles (or persons) pass a point during a specified time period less than one hour, expressed as an equivalent hourly rate.
3. *Demand* is the number of vehicles (or persons) that desire to travel past a point during a specified period (also usually one hour). Demand is frequently higher than actual volumes where congestion exists. Some trips divert to alternative routes, and other trips are simply not made.
4. *Capacity* is the maximum rate at which vehicles can traverse a point or short segment during a specified time period. It is a characteristic of the roadway. Actual volume can never be observed at levels higher than the true capacity of the section. However, such results may appear because capacity is most often estimated using standard analysis procedures of the *Highway Capacity Manual* [*1*]. These estimates may indeed be too low for some locations.

Techniques for collection, reduction, and presentation of volume (and other) traffic data were discussed in Chapter 8. This chapter presents techniques for statistical analysis of volume data and the interpretation and presentation of study results. It also provides an overview of typical volume characteristics found on most highway systems.

9.2 Volume, Demand, and Capacity

We have noted that volume, demand, and capacity are three different measures, even though all are expressed in the same units and may relate to the same location. In practical terms, volume is what *is*, demand is what motorists would like *to be*, and capacity is the physical limit of what *is possible*. In very simple terms, if vehicles were counted at any defined location for one hour:

- Volume would be the number of vehicles counted passing the study location in the hour.
- Demand would be the volume plus the vehicles of motorists wishing to pass the site during the study hour who were prevented from doing so by congestion. The latter would include motorists in queue waiting to reach the study location, motorists using alternative routes to avoid the congestion around the study location, and motorists deciding not to travel at all due to the existing congestion, or choosing to travel to an alternative destination.
- Capacity would be the maximum volume that could be accommodated by the highway at the study location.

Consider the illustration of Figure 9.1. It shows a classic bottleneck location on a freeway, in this case consisting of a major merge area. For each approaching leg, and for the downstream freeway section, the actual volume (v), the demand (d), and the capacity (c) of the segment are given. Capacity is the primary constraint on the facility. As shown in Figure 9.1, the capacity is 2,000 veh/h/ln, so that the capacity of the two-lane approach legs are 4,000 veh/h each, and the capacity of the downstream freeway, which has three lanes, is 6,000 veh/h.

Assuming that the stated capacities are correct, no volume in excess of these capacities can ever be counted. Simply put, you can't carry 6 gallons of water in a 5-gallon bucket. Therefore, it is informative to consider what would be observed for the situation as described. On Approach 1, the true demand is 3,800 veh/h and the capacity is 4,000 veh/h. On Approach 2, the true demand is 3,600 veh/h and the capacity is also 4,000 veh/h. There is no capacity deficiency on either approach. Downstream of the merge, however, the capacity is 6,000 veh/h, but the sum of the approaching demands is 3,800 + 3,600 = 7,400 veh/h. This exceeds the capacity of the segment.

Given this scenario, what can we expect to observe?

- Any volume count downstream of the merge cannot exceed 6,000 veh/h for as long as the illustrated conditions exist. A count of 6,000 veh/h is expected.
- Because of the capacity deficiency downstream of the merge, a queue of vehicles will begin to form and propagate upstream on both approaches.
- If a count of entering vehicles on both approaches is taken upstream of the forming queues, the true demand would be counted on each approach, assuming there has been no diversion of vehicles to alternative routes.
- If a count of approaching vehicles is taken within the forming queues, they would be unstable in both time and space, but their total should not exceed 6,000 veh/h, the capacity of the downstream freeway section.

A final question is also interesting: Given that queues are observed on both approaches, is it reasonable to assume

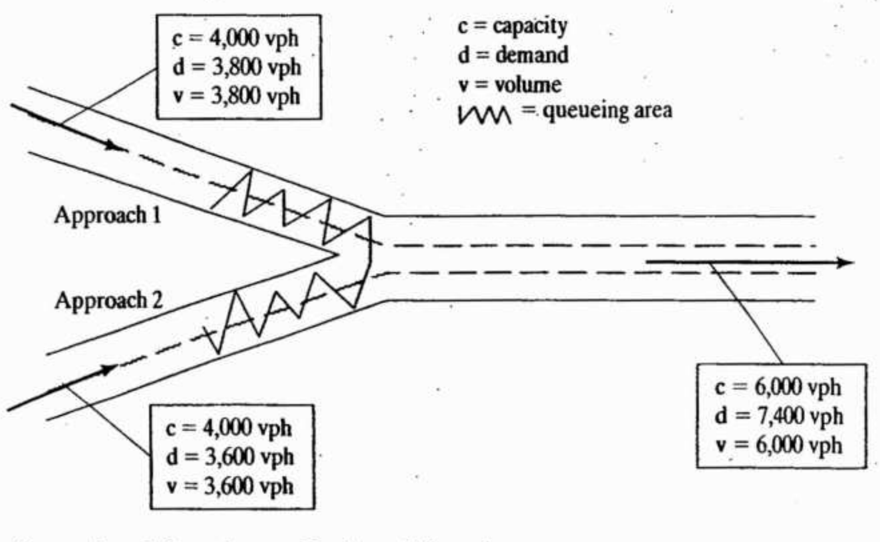


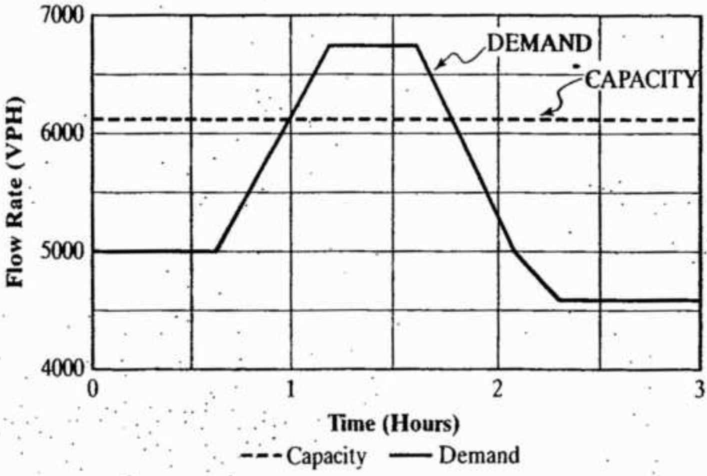
Figure 9.1: Volume, Demand, and Capacity at a Bottleneck Location

that the downstream count of 6,000 veh/h is a *direct measurement* of the capacity of the section? This issue involves a number of subtleties.

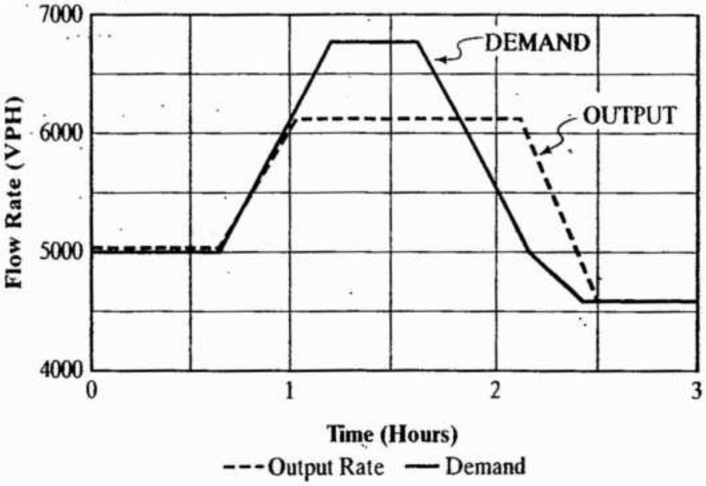
The existence of queues on both approaches certainly suggests that the downstream section has experienced capacity flow. Capacity, however, is defined as the maximum flow rate that can be achieved under stable operating conditions (i.e., without breakdown). Thus capacity would most precisely be the flow rate for the period immediately preceding the formation of queues. After the queues have formed, flow is in the "queue discharge" mode, and the flow rates and volumes measured may be equal to, less than, or even more than capacity. In practical terms, however, the queue discharge capacity may be more important than the stable-flow value, which is, in many cases, a transient that cannot be maintained for long periods of time.

As you can see from this illustration, volume (or rate of flow) can be counted anywhere and a result achieved. In a situation where queuing exists, it is reasonable to assume that downstream flows represent either capacity or queue discharge conditions. Demand, however, is much more difficult to address. Although queued vehicles can be added to counts, this is not necessarily a measure of true demand. True demand contains elements that go well beyond queued vehicles at an isolated location. Determining true demand requires an estimation of how many motorists changed their routes to avoid the subject location. It also requires knowledge of motorists who either traveled to alternative destinations or who simply decided to stay home (and not travel) as a result of congestion.

Figure 9.2 illustrates the impact of a capacity constraint on traffic counts. Part (a) shows a plot of demand and capacity. The demand shown would be observable if it were not



(a) Demand and capacity, as they would appear at the measurement point



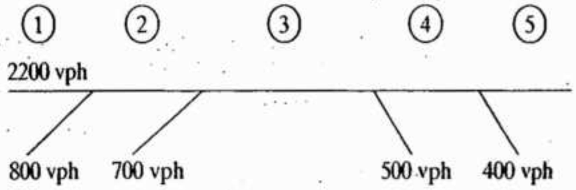
(b) Volume pattern distorted by capacity limit

Figure 9.2: A Simplified Analysis of Demand Exceeding Capacity

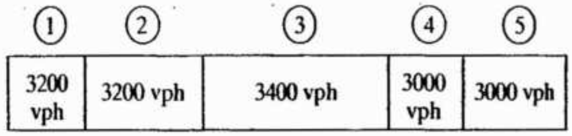
clear that a capacity constraint is present. Part (b) shows what will actually occur. Volume can never rise to a level higher than capacity. Thus actual counts peak at capacity. Because not all vehicles arriving can be accommodated, the peak period of flow is essentially lengthened until all vehicles can be served. The result is that observed counts will indicate that the peak flow rate is approximately the same as capacity and that it occurs over an extended period of time. The volume distribution looks as if someone took the demand distribution and flattened it out with their hand.

The difference between observed volume counts and true demand can have some interesting consequences when the difference is not recognized and included in planning and design. Figure 9.3 illustrates an interesting case of a freeway section consisting of four ramps.

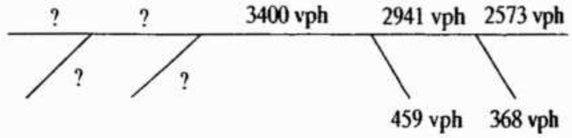
From Figure 9.3, the arriving demand volume on Segment 3 of 3,700 veh/h exceeds its capacity of 3,400 veh/h. From the point of view of counts taken within each segment, 3,400 veh/h will be observed in Segment 3. Because only 3,400 veh/h are output from Segment 3, the downstream counts in Segments 4 and 5 will be lower than their true demand. In this case, the counts shown reflect a proportional distribution of volume to the various ramps, using the same distribution as reflected in the demand values. The capacities of Segments 4 and 5 are not exceeded by these counts. Upstream counts in Segments 1 and 2 will be unstable and will reflect the transient state of the queue during the count period.



(a) True Demand



(b) Segment Capacities



(c) Observed Volumes

Figure 9.3: Effect of a Bottleneck on Observed Volumes

Assume that as a result of this study, a decision is made to add a lane to Segment 3, essentially increasing its capacity to a value larger than the demand of 3,700 veh/h. Once this is done, the volume now discharged into Segment 4 is 3,200 veh/h, more than the capacity of 3,000 veh/h. This secondary bottleneck, often referred to as a "hidden bottleneck," was not apparent in the volume data originally obtained. It was not obvious because the existing demand was constrained from reaching the segment due to an upstream bottleneck. Such a constraint is often referred to as "demand starvation."

In designing corrective highway improvements, it is critical that all downstream points be evaluated properly to identify such hidden bottlenecks. In the case illustrated, the improvement project would have to address *both* the existing and hidden bottlenecks to achieve a successful result.

The case of a freeway bottleneck is relatively simple to analyze because the number of entry and exit points are limited and the number of available alternative routes is generally small. On arterials, however, the situation is far more complex because every intersection represents a diversion opportunity, and the number of alternative routes is generally quite large. Thus the demand response to an arterial bottleneck is much harder to discern. An arterial may also have a number of overlapping bottlenecks, further complicating the analysis. If several consecutive signalized intersections, for example, are failing, it is difficult to trace the impacts. Is an upstream signal apparently failing because it is inadequate, or because a queue from the downstream signal has blocked the intersection?

On arterial systems, it is often impossible to measure existing demand, except in cases where there are no capacity constraints. Later in this chapter, a method for discerning intersection approach demand from observed volumes in a capacity-constrained case is discussed. It applies, however, only to an isolated breakdown and does not account for the effects of diversion. Congestion in a surface street network severely distorts demand patterns, and observed volumes are more a reflection of capacity constraints than true demand.

You should be aware that the terms *volume* and *demand* are often used imprecisely, even in the technical literature. It is often necessary to discern the true meaning of these terms from the context in which they are used.

In the final analysis, volume counts always result in an observation of "volume." Depending on the circumstances, observed volumes may be equivalent to demand, to capacity, or to neither. The traffic engineer must, however, gain sufficient insight through counting studies and programs to recognize which situation exists and to incorporate this properly into the interpretation of the study data and the development of improvement plans.

9.3 Volume Characteristics

If traffic distributed itself uniformly among the 365 × 24 = 8,760 hours of the year, there is not a location in the nation that would experience congestion or significant delay. The problem for traffic engineers, of course, is that there are strong peaks during a typical day, caused primarily by commuters going to and from work. Depending on the specific region and location, the peak hour of the day typically contains from 9% to 15% of the 24-hour volume. In remote or rural areas, the percentage can go much higher, but the volumes are much lower in these surroundings.

The traffic engineer, therefore, must deal with the travel preferences of our society in planning, designing, and operating highway systems. In some dense urban areas, policies to induce spreading of the peak have been attempted, including the institution of flex-hours or days and/or variable pricing policies for toll and parking facilities. Nevertheless, the traffic engineer must still face the fundamental problem: Traffic demand varies in time in ways that are quite inefficient. Demand varies by time of day, by day of the week, by month or season of the year, and in response to singular events (both planned and unplanned) such as construction detours, accidents or other incidents, and even severe weather. Modern intelligent transportation system (ITS) technologies increasingly try to manage demand on a real-time basis by providing information on routes, current travel times, and related conditions directly to drivers. This is a rapidly growing technology sector, but its impacts have not yet been well documented.

One of the many reasons for doing volume studies is to document these complex variation patterns and to evaluate the impact of ITS technologies and other measures on traffic demand.

9.3.1 Hourly Traffic Variation Patterns: The Phenomenon of the Peak Hour

When hourly traffic patterns are contemplated, we have been conditioned to think in terms of two "peak hours" of the day: morning and evening. Dominated by commuters going to work in the morning (usually between 7 AM and 10 AM) and returning in the evening (usually between 4 PM and 7 PM), these patterns tend to be repetitive and more predictable than other facets of traffic demand. This so-called typical pattern holds only for weekday travel, and modern evidence may suggest that this pattern is not as typical as we have been inclined to accept.

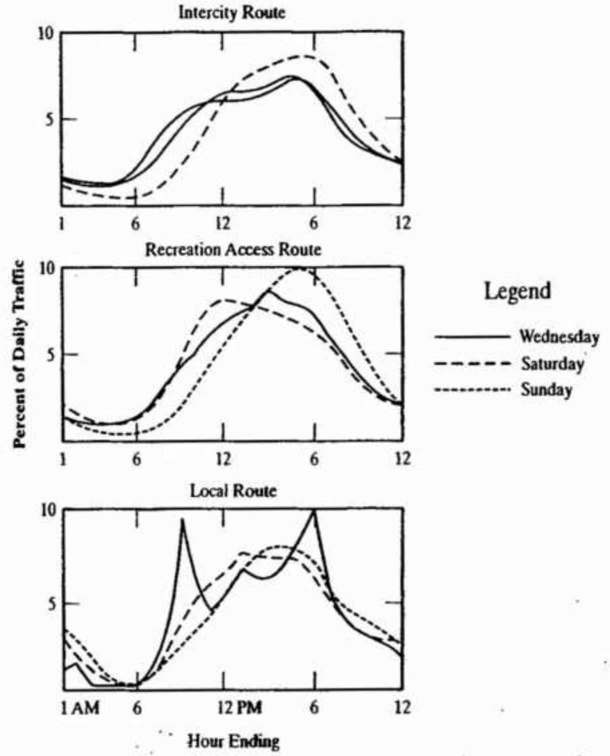
Figure 9.4 shows a number of hourly variation patterns documented in the *Highway Capacity Manual* [*1*], compiled from References 2 and 3. In part (a) of Figure 9.4, hourly distributions for rural highways are depicted. Only the weekday pattern on a local rural route displays the expected AM and PM peak patterns. Intercity, recreational, and local weekend traffic distributions have only a single, more dispersed peak occurring across the mid- to late afternoon. In part (b), weekday data from four urban sites are shown in a single direction. Sites 1 and 3 are in the opposite direction from Sites 2 and 4, which are only two blocks apart on the same facility. Whereas Sites 2 and 4 show clear AM peaks, traffic after the peak stays relatively high and surprisingly uniform for most of the day. Sites 1 and 3, in the opposite direction, show evening peaks, with Site 3 also displaying considerable off-peak hour traffic volume. Only Site 1 shows a strong PM peak with significantly less traffic during other portions of the day.

The absence of clear AM and PM peaks in many major urban areas is a spreading phenomenon. On one major facility, the Long Island Expressway (I-495) in New York, a recent study showed that on a typical weekday, only one peak was discernible in traffic volume data—and it lasted for 10 to 12 hours per day. This characteristic is a direct result of system capacity constraints. Everyone who would like to drive during the normal peak hours cannot be accommodated. Because of this, individuals begin to make travel choices that allow them to increasingly travel during the "off-peak" hours. This process continues until off-peak periods are virtually impossible to separate from peak periods.

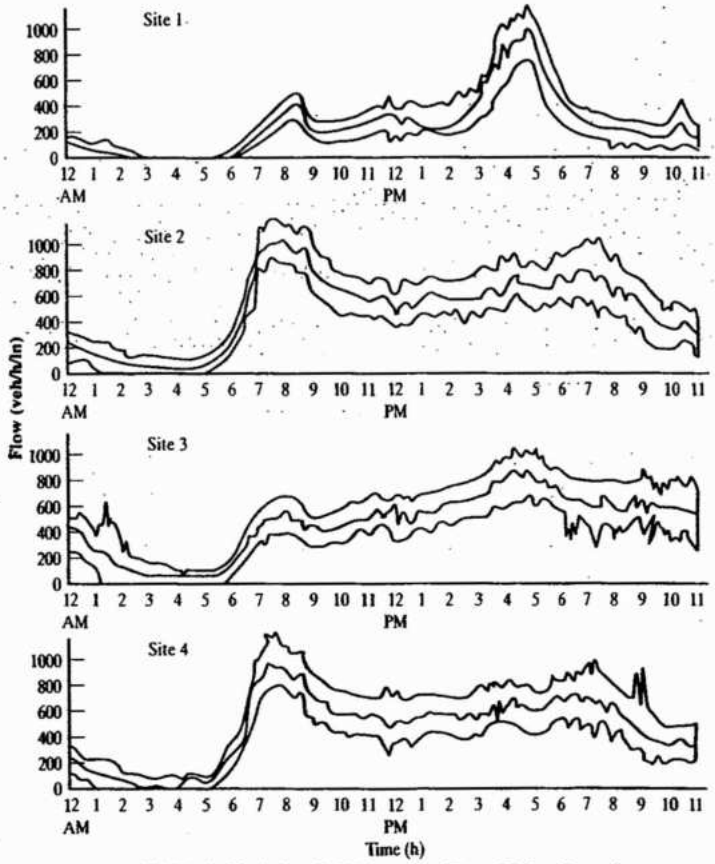
Figure 9.4 (b) displays another interesting characteristic of note. The outer lines of each plot show the 95% confidence intervals for hourly volumes over the course of one year. Traffic engineers depend on the basic repeatability of peak-hour traffic demands. The variation in these volumes in Figure 9.4 (b), however, is not insignificant. During the course of any given year, there are 365 peak hours at any location, one for each day of the year. This is question for the traffic engineer: Which one should be used for planning, design, and operations?

Figure 9.5 shows plots of peak-hour volumes (as a percentage of annual average daily travel [ADT]) in decreasing order for a variety of facilities in Minnesota. In all cases, there is clearly a "highest" peak hour of the year. The difference between this highest peak and the bulk of the year's peak hours, however, depends on the type of facility. The recreational route has the greatest disparity.

This is not unexpected because traffic on such a route will tend to have enormous peaks during the appropriate season on weekends, with far less traffic on a "normal" day. The main rural route has less of a disparity, as at least some component of traffic consists of regular commuters. Urban roadways show far less of a gap between the highest hour and the bulk of peak hours.



(a) Typical Variations for Rural Routes



(b) Daily Variation in Volumes at Four Urban Locations

Figure 9.4: Examples of Hourly Volume Variation Patterns

(*Source:* Used with permission of Transportation Research Board, *Highway Capacity Manual*, 4th Edition, Washington DC, 2000, Exhibits 8-6 and 8-7, pp. 8-6 and 8-7, repeated from References 2 and 3.)

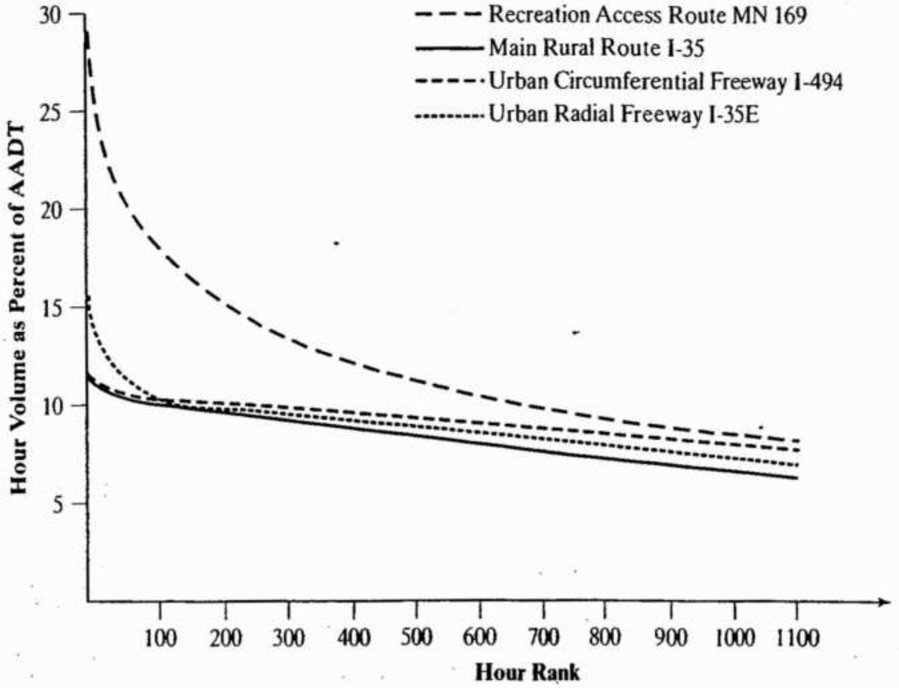


Figure 9.5: Peak Hours as a Percentage of AADT

(*Source:* Used with permission of Transportation Research Board, *Highway Capacity Manual,* 4th Edition, Washington DC, 2000, Exhibit 8-8, p. 8-8.)

It is interesting to examine the various peak hours for the types of facilities illustrated in Figure 9.5, which represents data from various facilities in Minnesota. Table 9.1 tabulates the percentage of AADT occurring within designated peak hours for the facility types represented.

The choice of which peak hour to use as a basis for planning, design, and operations is most critical for the recreational access route. In this case, the highest hour of the year carries twice as much traffic as the 200th peak hour of the year and 1.36 times that of the 30th hour of the year. In the two urban cases, the highest hour of the year is only 1.2 times the 200th highest hour.

Historically, the 30th highest hour has been used in rural planning, design, and operations. There are two primary arguments for such a policy: (1) the target demand would be exceeded only 29 times per year, and (2) the 30th peak hour generally marks a point where subsequent peak hours have similar volumes. The latter defines a point on many relationships where the curve begins to "flatten out," a range of demands where it is deemed economic to invest in additional roadway capacity.

In urban settings, the choice of a design hour is far less clear and has far less impact. Typical design hours selected range from the 30th highest hour to the 100th highest hour. For the facilities of Figure 9.5, this choice represents a range from 10.5% to 10.0% of AADT. With an AADT of 80,000 veh/day, for example, this range is a difference of only 400 veh/h in demand.

Table 9.1: Key Values from Figure 9.5

	Percent of AADT Occurring in the ___ Peak Hour			
Type of Facility	**1st**	**30th**	**100th**	**200th**
Recreational Access	30.0%	22.0%	18.0%	15.0%
Main Rural	15.0%	13.0%	10.0%	9.0%
Urban Circumferential Freeway	11.5%	10.5%	10.0%	9.5%
Urban Radial Freeway	11.5%	10.5%	10.0%	9.5%

9.3.2 Subhourly Variation Patterns: Flow Rates Versus Volumes

In Chapter 5, we noted that peaking of traffic flows within the peak hour often needed to be considered in design and operations. The peak hour factor (PHF) was defined as a means of quantifying the difference between a maximum flow rate and the hourly volume within the peak hour. Figure 9.6 shows the difference among 5-minute, 15-minute, and peak hourly flow rates from a freeway location in Minnesota.

Flow rates can be measured for almost any period of time. For research purposes, periods from one to five minutes have frequently been used. Very small increments of time, however, become impractical at some point. In a two-second interval, the range of volumes in a given lane would be limited to "0" or "1," and flow rates would be statistically meaningless.

For most traffic engineering applications, 15 minutes is the standard time period used, primarily based on the belief that this is the shortest period of time over which flow rates are "statistically stable." Statistically stable implies that reasonable relationships can be calibrated among flow parameters, such as flow rate, speed, and density. In recent years, there is some thought that five-minute flow rates might qualify as statistically stable, particularly on freeway facilities. Practice, however, continues to use 15 minutes as the standard period for flow rates.

The choice, however, has major implications. In Figure 9.6, the highest 5-minute rate of flow is 2,200 veh/h/ln; the highest 15-minute rate of flow is 2,050 veh/h/ln; the peak hour volume is 1,630 veh/h/ln. Selecting a 15-minute base period for design and analysis means that, in this case, the demand flow rate (assuming no capacity constraints) would be 2,050 veh/h/ln. This value is 7% lower than the peak five-minute flow rate and 20% higher than the peak-hour volume. In real design terms, these differences could translate into a design with one more or fewer lanes or differences in other geometric and control features. The use of 15-minute flow periods also implies that breakdowns of a shorter duration do not cause the kinds of instabilities that accompany breakdowns extending for 15 minutes or more.

9.3.3 Daily Variation Patterns

Traffic volumes also conform to daily variation patterns that are caused by the type of land uses and trip purposes served by the facility. Figure 9.7 illustrates some typical relationships.

The recreational access route displays strong peaks on Fridays and Sundays. This is a typical pattern for such routes because motorists leave the city for recreational areas on Fridays, returning on Sundays. Mondays through Thursdays have far less traffic demand, although Monday is somewhat higher than other weekdays due to some vacationers returning after the weekend rather than on Sunday.

The suburban freeway obviously caters to commuters. Commuter trips are virtually a mirror image of recreational trips, with peaks occurring on weekdays and lower demand on weekends. The main rural route in this exhibit has a pattern similar to the recreational route but with less variation between the weekdays and weekends. The route serves both recreational and commuter trips, and the mix tends to dampen the amount of variation observed.

9.3.4 Monthly or Seasonal Variation Patterns

Figure 9.8 illustrates typical monthly volume variation patterns. Recreational routes will have strong peaks occurring during the appropriate seasons (i.e., summer for beaches, winter for skiing). Commuter routes often show similar patterns with less variability. In Figure 8.8, recreational routes display monthly ADTs that range from 77% to 158% of the AADT. Commuter routes, although showing similar peaking periods, have monthly ADTs ranging from 82% to 119% of AADT.

It might be expected that commuter routes would show a trend opposite to recreational routes (i.e., if recreational routes are peaking in the summer, then commuter routes should have less traffic during those periods). The problem is that few facilities are purely recreational or commuter; there is always some mix present. Further, much recreational travel is done by inhabitants of the region in question; the same motorists may be part of both the recreational and commuter demand during the same months. There are, however, some areas in which commuter traffic does clearly decline during summer recreational months. The distributions shown here are illustrative; different distributions are possible, and they do occur in other regions.

9.3.5 Some Final Thoughts on Volume Variation Patterns

One of the most difficult problems in traffic engineering is that we are continually planning and designing for a demand that represents a peak flow rate within a peak hour on a peak day during a peak season. When we are successful, the resulting facilities are underused most of the time.

It is only through the careful documentation of these variation patterns, however, that the traffic engineer can know the impact of this underutilization. Knowing the volume variation patterns governing a particular area or location is critical to

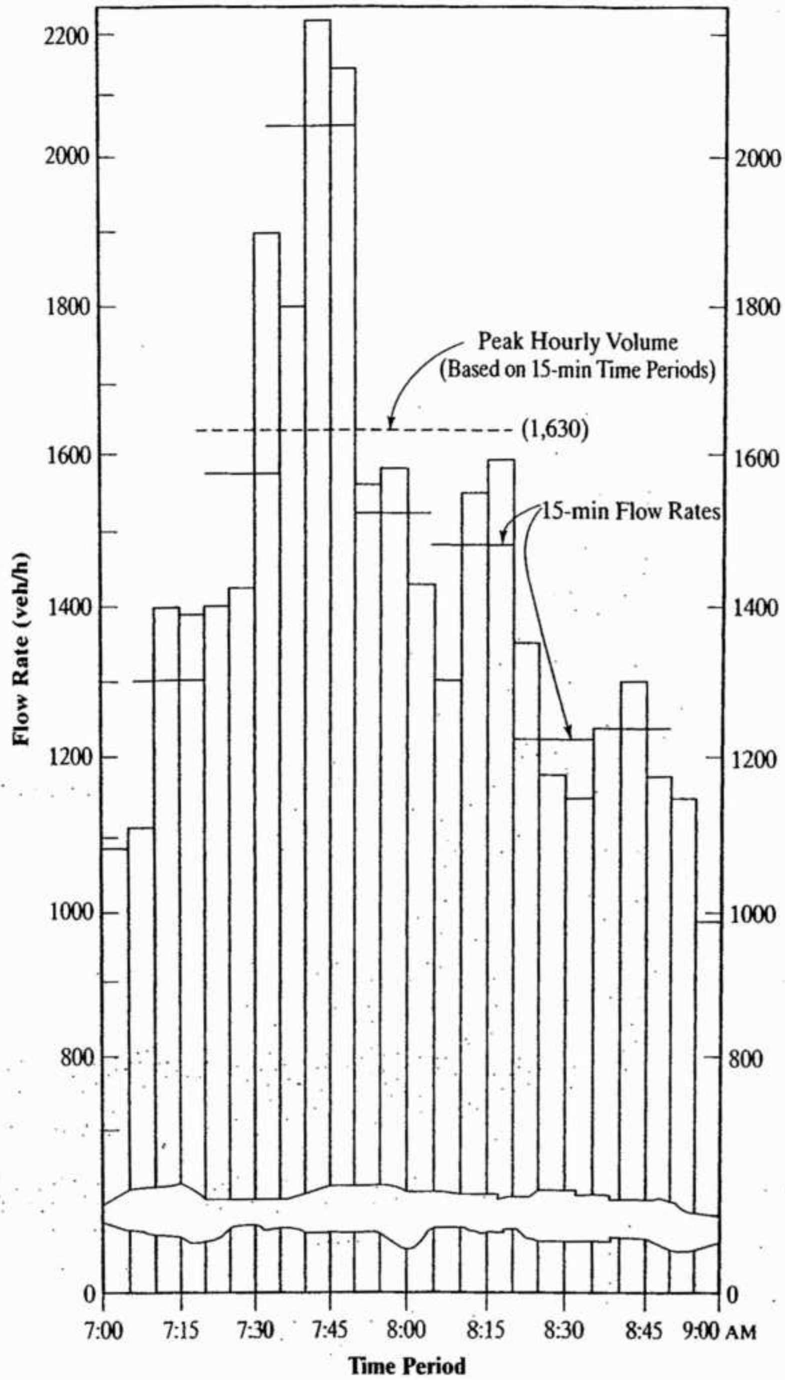


Figure 9.6: Variations of Flow Within the Peak Hour

(*Source:* Used with permission of Transportation Research Board, *Highway Capacity Manual*, 4th Edition, Washington DC, 2000, Fig 8-10, p. 8-10.)

finding appropriate design and control measures to optimize operations. It is also important to document these patterns so that estimates of an AADT can be discerned from data taken for much shorter time periods. It is simply impractical to count every location for a full year to determine AADT and related demand factors. Counts taken over a shorter period of time can, however, be adjusted to reflect a yearly average or a peak occurring during another part of the year, if the variation patterns are known and well documented. These concepts are illustrated and applied in the sections that follow.

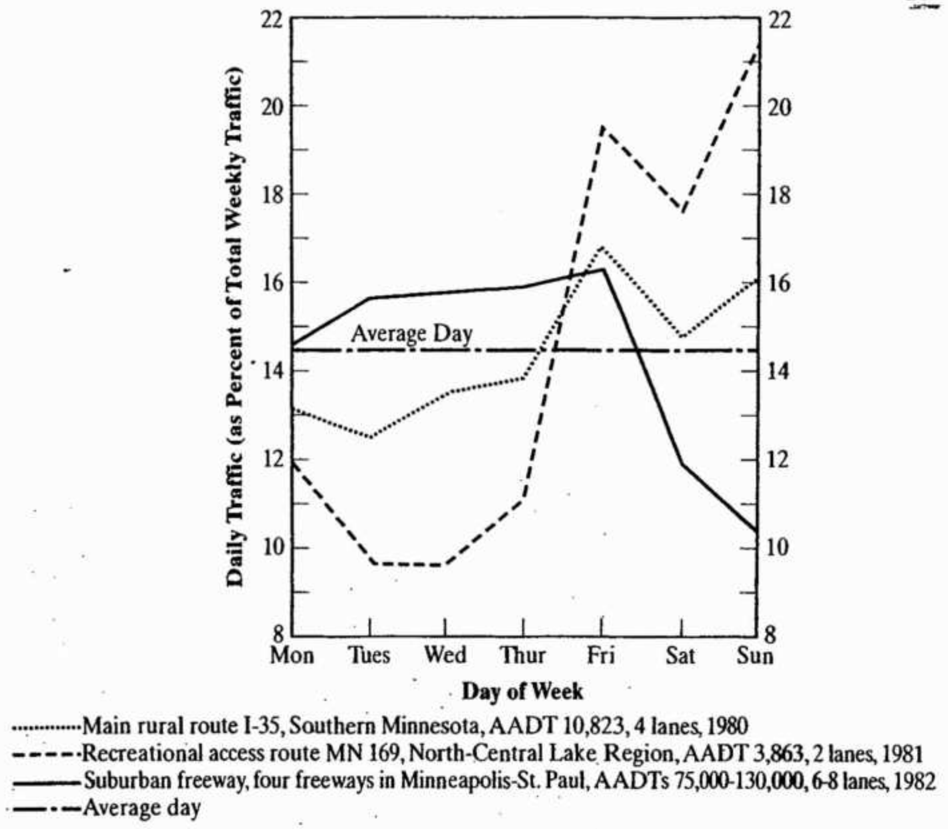


Figure 9.7: Typical Daily Volume Variation Patterns

(*Source:* Used with permission of Transportation Research Board, *Highway Capacity Manual*, 4th Edition, Washington DC, 2000, Exhibit 8-4, p. 8-5.)

9.4 Intersection Volume Studies

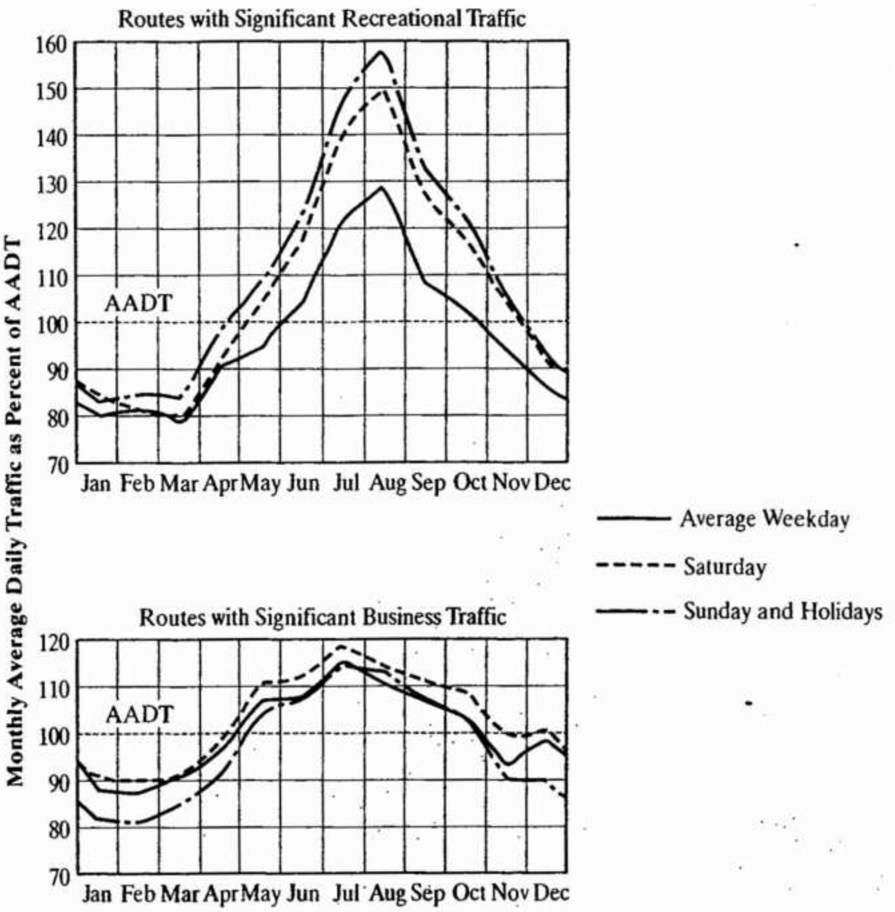
No single location is more complex in a traffic system than an at-grade intersection. At a typical four-leg intersection, there are 12 separate movements—left, through, and right from each leg. If a count of intersection volumes is desired, with each movement classified by cars, taxis, trucks, and buses, each count period requires the observation of 12 × 4 = 48 separate pieces of data.

When intersections are counted manually (and they often are), observers must be positioned properly to see the movements they are counting. It is doubtful that an inexperienced counter could observe and classify more than one major or two minor movements simultaneously. For heavily used multilane approaches, it may be necessary to use separate observers for different lanes. In manual intersection studies, short-break and alternating-period approaches are almost always combined to reduce the number of observers needed. Rarely, however, can an intersection be counted with fewer than four observers, plu one crew chief to time count periods and breaks.

9.4.1 Arrival Versus Departure Volumes: A Key Issue for Intersection Studies

At most intersections, volumes are counted as they depart the intersection. This is done both for convenience and because turning movements cannot be fully resolved until vehicles exit the intersection. Although this approach is fine where there is no capacity constraint (i.e., an unstable buildup of queues on the approach), it is not acceptable where demand exceeds the capacity of the approach. In such cases, it is necessary to observe *arrival* volumes because these are a more accurate reflection of demand.

At signalized intersections, "unstable queue buildup" is detected when vehicles queued during a red interval are not full


Routes with Significant Recreational Traffic

Routes with Significant Business Traffic

Figure 9.8: Typical Monthly Variation Patterns

(*Source:* Used with permission of Transportation Research Board, *Highway Capacity Manual*, 4th Edition, Washington DC, 2000, Exhibit 8-2, p. 8-3.)

cleared during the next green interval. At unsignalized intersections, "unstable queue buildup" can be identified by queues that become larger during each successive counting period.

Direct observation of arrival volumes at an intersection is difficult because the queue is dynamic. As the queue grows and declines, the point of "arrival" changes. Therefore, the technique used to count arrival volumes is to count departure volumes and the number of queued vehicles at periodic intervals. For signalized approaches, the size of the queue would be recorded *at the beginning of each red phase.* This identifies the "residual queue" of vehicles that arrived during the previous signal cycle but were not serviced. For unsignalized approaches, the queue is counted at the end of each count period. When such an approach is followed, the arrival volume is estimated as follows:

$$V_{ai} = V_{di} + N_{qi} - N_{q(i-1)} \qquad (9\text{-}1)$$

where: V_{ai} = arrival volume during period i, vehs
V_{di} = departure volume during period i, vehs
N_{qi} = number of queued vehicles at the end of period i, vehs
$N_{q(i-1)}$ = number of queued vehicles at the end of period i-1, vehs

Estimates of arrival volume using this procedure identify only the localized arrival volume. This procedure *does not* identify diverted vehicles or the number of trips that were not made due to general congestion levels. Thus although arrival volumes do represent localized demand, they do not measure diverted or repressed demand. Table 9.2 shows sample study data using this procedure to estimate arrival volumes.

Note that the study is set up so the first and last count periods do not have residual queues. Also, the total departure and arrival counts are the same, but the conversion from

Table 9.2: Estimating Arrival Volumes from Departure Counts: An Example

Time Period (PM)	Departure Count (vehs)	Queue Length (vehs)	Arrival Volume (vehs)
4:00–4:15	50	0	50
4:15–4:30	55	0	55
4:30–4:45	62	5	$62 + 5 = 67$
4:45–5:00	65	10	$65 + 10 - 5 = 70$
5:00–5:15	60	12	$60 + 12 - 10 = 62$
5:15–5:30	60	5	$60 + 5 - 12 = 53$
5:30–5:45	62	0	$62 - 5 = 57$
5:45–6:00	55	0	55
Total	**469**		**469**

departures to arrivals causes a shift in the distribution of volumes by time period. Based on departure counts, the maximum 15-minute volume is 65 vehicles, or a flow rate of 65/0.25 = 260 veh/h. Using arrival counts, the maximum 15-minute volume is 70, or a flow rate of 70/0.25 = 280 veh/h. The difference is important because the higher arrival flow rate (assuming that the study encompasses the peak period) represents a value that would be valid for use in planning, design, or operations.

9.4.2 Special Considerations for Signalized Intersections

At signalized intersections, count procedures are both simplified and more complicated at the same time. For manual observers, the signalized intersection simplifies counting because not all movements are flowing at the same time. An observer who can normally count only one through movement at a time could actually count two such movements in the same count period by selecting, for example, the eastbound and northbound through movements. These two operate during different phases of the signal.

Count periods at signalized intersections, however, must be equal multiples of the cycle length. Further, actual counting times (exclusive of breaks) must also be equal multiples of the cycle length. This is to guarantee that all movements get the same number of green phases within a count period. Thus, for a 60-second signal cycle, a 4 of 5-minute counting procedure may be employed. For a 90-second cycle, however, neither 4 nor 5 minutes are equal multiples of 90 seconds (1.5 minutes). For a 90-second cycle, a counting process of 12 of 15 minutes would be appropriate, as would 4.5 of 6 minutes.

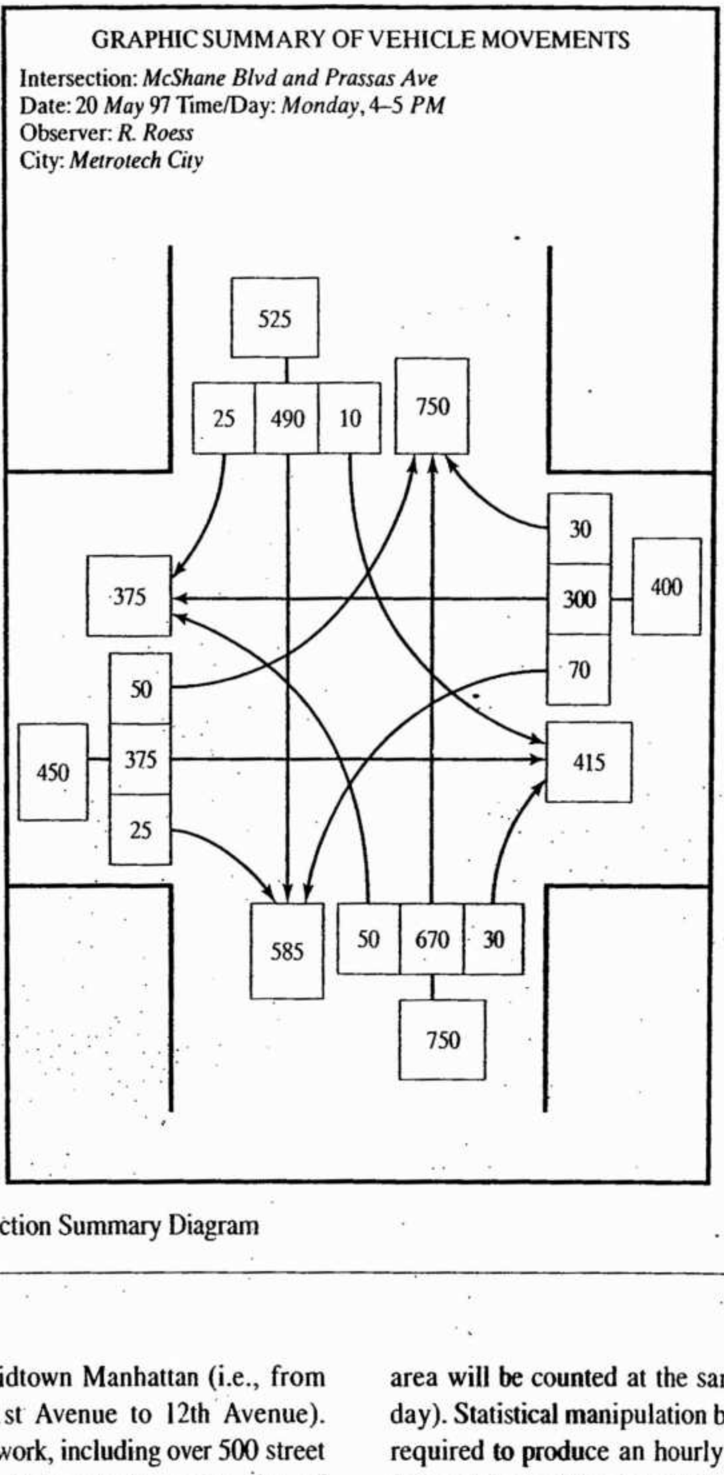
Actuated signals present special problems because both cycle lengths and green splits vary from cycle to cycle. Count periods are generally set to encompass a minimum of five signal cycles, using the maximum cycle length as a guide. The actual counting sequence is arbitrarily chosen to reflect this principle, but it is not possible to assure equal numbers of phases for each movement in each count period. This is not viewed as a major difficulty because the premise of actuated signalization is that green times should be allocated proportionally to vehicle demands present during each cycle.

9.4.3 Presentation of Intersection Volume Data

Intersection volume data may be summarized and presented in a variety of ways. Simple tabular arrays can summarize counts for each count period by movement. Breakdowns by vehicle type are also most easily depicted in tables. More elaborate graphic presentations are most often prepared to depict peak-hour and/or full-day volumes. Figures 9.9 and 9.10 illustrate common forms for display of peak-hour or daily data. The first is a graphic intersection summary diagram that allows simple entry of data on a predesigned graphic form. The second is an intersection flow diagram in which the thickness of flow lines is based on relative volumes.

9.5 Limited Network Volume Studies

Consider the following proposition: A volume study is to be made covering the period from 6 AM to 12 midnight on the



GRAPHIC SUMMARY OF VEHICLE MOVEMENTS

Intersection: *McShane Blvd and Prassas Ave*
Date: 20 *May 97* Time/Day: *Monday*, 4–5 *PM*
Observer: *R. Roess*
City: *Metrotech City*

Figure 9.9: Graphic Intersection Summary Diagram

et network comprising midtown Manhattan (i.e., from h Street to 59th Street, 1st Avenue to 12th Avenue). hough this is a very big network, including over 500 street ks and 500 intersections, it is not the entire city of w York, nor is it a statewide network.

Nevertheless, the size of the network is daunting for a ple reason: It is virtually impossible to acquire and train ficient personnel to count all of these locations at the e time. Further, it would be impractically expensive to and acquire sufficient portable counting equipment to do To conduct this study, it will be necessary to employ *pling* techniques (i.e., not all locations within the study area will be counted at the same time or even on the same day). Statistical manipulation based on these samples will be required to produce an hourly volume map of the network for each hour of the intended survey period, or for an average peak period.

Such "limited" networks exist in both small towns and large cities and around other major trip generators, such as airports, sports facilities, shopping malls, and other activity centers. Volume studies on such networks involve individual planning and some knowledge of basic characteristics, such as location of major generators and the nature of traffic on various facilities (local versus through users, for example).

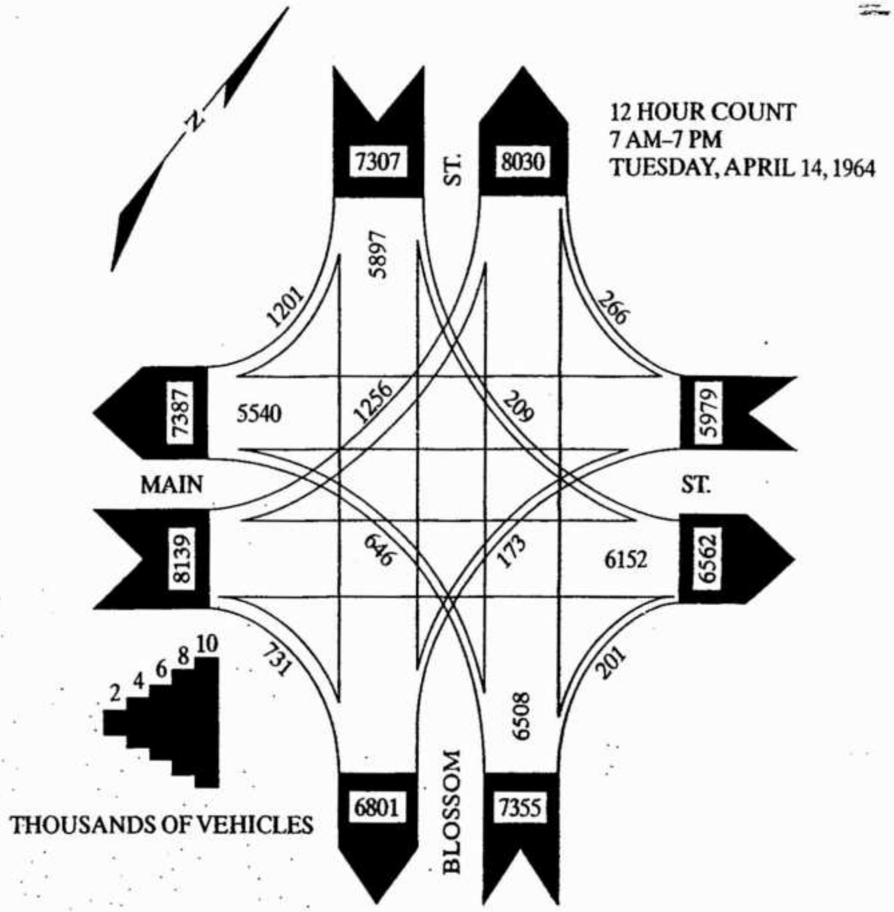


Figure 9.10: An Intersection Flow Diagram

(*Source:* Used with permission of Institute for Transportation Engineers, *Transportation and Traffic Engineering Handbook,* 1st Edition, Washington DC, 1976, p. 410.)

The establishment of a reasonable sampling methodology will require judgment based on such local familiarity.

Sampling procedures rely on the assumption that entire networks, or identifiable subportions of networks, have similar demand patterns in time. If these patterns can be measured at a few locations, the pattern can be superimposed on sample measurements from other locations in the network. To implement such a procedure, two types of counts are conducted:

- *Control counts.* Control counts are taken at selected representative locations to measure and quantify demand variation patterns in time. In general, control counts must be maintained continuously throughout the study period.
- *Coverage counts.* Coverage counts are taken at all locations for which data is needed. They are conducted as samples, with each location being counted for only a portion of the study period, in accordance with a preestablished sampling plan.

These types of counts and their use in volume analysis are discussed in the sections that follow.

9.5.1 Control Counts

Because control counts will be used to expand and adjust the results of coverage counts throughout the network under study, it is critical that representative control-count locations be properly selected. The hourly and daily variation patterns observed at a control count must be representative of a larger portion of the network if the sampling procedure is to be accurate and meaningful. Remember that volume variation patterns are generated by land-use characteristics and by the e of traffic, particularly the percentages of through versus ally generated traffic in the traffic stream. With these nciples in mind, some general guidelines can be used in the ection of appropriate control-count locations:

1. There should be one control-count location for every 10 to 20 coverage-count locations to be sampled.
2. Different control-count locations should be established for each class of facility in the network—local streets, collectors, arterials, and so on, because different classes of facilities serve different mixes of through and local traffic.
3. Different control-count locations should be established for portions of the network with markedly different land-use characteristics.

These are only general guidelines. The engineer must rcise judgment and use his or her knowledge of the area der study to identify appropriate control-count locations.

5.2 Coverage Counts

l locations at which sample counts will be taken are called *verage counts.* All coverage counts (and control counts as ll) in a network study are taken at midblock locations to oid the difficulty of separately recording turning movents. Each link of the network is counted at least once dur the study period. Intersection turning movements may be proximately inferred from successive link volumes, and, when necessary, supplementary intersection counts can be taken. Counts at midblock locations allow for the use of portable automated counters, although the duration of some coverage counts may be too short to justify their use.

9.5.3 An Illustrative Study

The types of computations involved in expanding and adjusting sample network counts is best described by a simple example. Figure 9.11 shows one segment of a larger network that has been identified as having reasonably uniform traffic patterns in time. The network segment has seven links, one of which has been established as a control-count location. Each of the other six links are coverage-count locations at which sample counts will be conducted. The various proposed study procedures all assume there are only two field crews or automated counters that can be employed simultaneously in this segment of the network. A study procedure is needed to find the volume on each link of the network between 12 noon and 8:00 PM on a typical weekday. Three different approaches are discussed. They are typical and not the only approaches that could be used. However, they illustrate all of the expansion and adjustment computations involved in such studies.

A One-Day Study Plan

It is possible to complete the study in a single day. One of the two available crews or setups would be used to count Control Location A for the entire eight-hour period of the study.

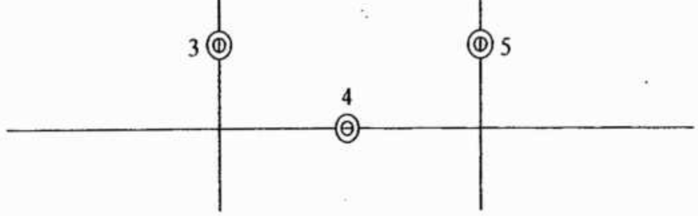


Figure 9.11: A Sample Network Volume Study

The second crew or set-up would be used to count each of Coverage Locations 1 to 6 for one hour. Table 9.3 shows the sample data and analysis resulting from this approach.

Note that full-hour data is shown. This data reflects expansion of actual counts for break periods. If machine counts were conducted, they would also reflect the conversion of axle counts to vehicle counts.

In Table 9.3 (b), the control-count data are used to quantify the hourly variation pattern observed. It is now assumed that this pattern applies to all of coverage locations

Table 9.3: Data and Computations for a One-Day Network Volume Study

Control-Count Data Location A		Coverage-Count Data		
Time (PM)	**Count (vehs)**	**Location**	**Time (PM)**	**Count (vehs)**
12–1	825	1	12–1	840
1–2	811	2	1–2	625
2–3	912	3	2–3	600
3–4	975	4	4–5	390
4–5	1,056	5	5–6	1,215
5–6	1,153	6	6–7	1,440
6–7	938			
7–8	397			

(a) Data from a One-Day Study

Time (PM)	Count (vehs)	Proportion of 8-Hour Total
12–1	825	825/7,067 = 0.117
1–2	811	811/7,067 = 0.115
2–3	912	912/7,067 = 0.129
3–4	975	975/7,067 = 0.138
4–5	1,056	1,056/7,067 = 0.149
5–6	1,153	1,153/7,067 = 0.163
6–7	938	938/7,067 = 0.133
7–8	397	397/7,067 = 0.056
Total	**7,067**	**1.000**

(b) Computation of Hourly Volume Proportions From Control-Count Data

Location	Time (PM)	Count (vehs)	Estimated 8-Hr Volume (vehs)	Estimated Peak Hour Volume (vehs)
1	12–1	840	840/0.117 = 7,179	× 0.163 = 1,170
2	1–2	625	625/0.115 = 5,435	× 0.163 = 886
3	2–3	600	600/0.129 = 4,651	× 0.163 = 758
4	4–5	390	390/0.149 = 2,617	× 0.163 = 427
5	5–6	1,215	1,215/0.163 = 7,454	× 0.163 = 1,215
6	6–7	1,440	1,440/0.133 = 10,827	× 0.163 = 1,765

(c) Expansion of Hourly Counts

within the network. Thus a count of **840** vehicles at location 1 would represent 0.117 (or 11.7%) of the eight-hour total at this location. The eight-hour total can then be estimated as 840/0.117 = 7,179 vehicles. Moreover, the peak-hour volume can be estimated as 0.163 × 7,179 = 1,170 vehicles because the hourly distribution shows that the highest volume hour contains 0.163 (or 16.3%) of the eight-hour volume. Note that this expansion of data results in estimates of eight-hour and peak-hour volumes at each of the seven count locations that represent *the day on which the counts were taken*. Daily and seasonal variations have not been eliminated by this study technique. Volumes for the entire network, however, have been estimated for common ime periods.

A Multiday Study

n the one-day study approach, each coverage location was ounted for one hour. Based on hourly variation patterns locumented at the control location, these counts were xpanded into eight-hour volume estimates. Hourly variation atterns, however, are not as stable as variations over larger eriods of time. For this reason, it could be argued that a etter approach would be to count each coverage location for full eight hours.

Given the limitation to two simultaneous counts due to ersonnel and/or equipment, such a study would take place ver six days. One crew would monitor the control location r the entire period of the study, and the second would count one coverage location for eight hours on each of six days.

The data and computations associated with a 6-day udy are illustrated in Table 9.4. In this case, hourly tterns do not have to be modeled because each coverage cation is counted for every hour of the study period. nfortunately, the counts are spread over six days, over hich volume may vary considerably at any given location. this case, the control data are used to quantify the undering *daily* variation pattern. These data are used to *adjust* e coverage data.

Daily volume variations are quantified in terms of ljustment factors defined as follows: the volume for a given y multiplied by the factor yields a volume for the average y of the study period. Stated mathematically:

$$V_a = V_i F_{vi} \qquad (9\text{-}2)$$

ere V_a = for the average day of the study period, veh

V_i = for day i

F_{vi} = factor for day i

Using data from the control location, at which the average volume will be known, adjustment factors for each day of the study may be computed as:

$$F_{vi} = V_a / V_i \qquad (9\text{-}3)$$

where all terms are as previously defined. Factors for the sample study are calibrated in Table 9.4 (b). Coverage counts are adjusted using Equation 9-2 in Table 9.4 (c).

The results represent the average eight-hour volumes for all locations for the six-day period of the study. Seasonal variations are not accounted for, nor are weekend days, which were excluded from the study.

A Mixed Approach: A Three-Day Study

The first two approaches can be combined. If a one-day study is not deemed appropriate due to the estimation of eight-hour volumes based on one-hour observations, and the six-day study is too expensive, a three-day study program can be devised in which each coverage location is counted for four hours on one of three days. The control location would have to be counted for the entire three-day study period; results would be used to calibrate the distribution of volume by four-hour period and by day.

In this approach, four-hour coverage counts must be (1) expanded to reflect the full eight-hour study period, and (2) adjusted to reflect the average day of the three-day study period. Table 9.5 illustrates the data and computations for the three-day study approach.

Note that in expanding the four-hour coverage counts to eight hours, the proportional split of volume varied from day to day. The expansions used the proportion appropriate to the day of the count. Because the variation was not great, however, it would have been equally justifiable to use the average hourly split for all three days.

Again, the results obtained represent the particular three-day period over which the counts were conducted. Volume variations involving other days of the week or seasonal factors are not considered.

The three approaches detailed in this section are illustrative. Expansion and adjustment of coverage counts based on control observations can be organized in many different ways, covering any network size and study period. The selection of control locations involves much judgment, and the success of any particular study depends on the quality of the judgment exercised in designing the study. The traffic engineer must design each study to achieve the particular information goals at hand.

Table 9.4: Data and Computations for a Six-Day Study Option

Control-Count Data Location A		Coverage-Count Data		
Day	8-Hour Count (vehs)	Coverage Location	Day	8-Hour Count (vehs)
Monday 1	7,000	1	Monday 1	6,500
Tuesday	7,700	2	Tuesday	6,200
Wednesday	7,700	3	Wednesday	6,000
Thursday	8,400	4	Thursday	7,100
Friday	7,000	5	Friday	7,800
Monday 2	6,300	6	Monday 2	5,400

(a) Data for a Six-Day Study

Day	8-Hour Count (vehs)	Adjustment Factor
Monday 1	7,000	7,350/7,000 = 1.05
Tuesday	7,700	7,350/7,700 = 0.95
Wednesday	7,700	7,350/7,700 = 0.95
Thursday	8,400	7,350/8,400 = 0.88
Friday	7,000	7,350/7,000 = 1.05
Monday 2	6,300	7,350/6,300 = 1.17
Total	44,100	
Average	44,100/6 = 7,350	

(b) Computation of Daily Adjustment Factors

Station	Day	8-Hour Count (vehs)	Adjusted 8-Hour Count (vehs)
1	Monday 1	6,500	× 1.05 = 6,825
2	Tuesday	6,200	× 0.95 = 5,890
3	Wednesday	6,000	× 0.95 = 5,700
4	Thursday	7,100	× 0.88 = 6,248
5	Friday	7,800	× 1.05 = 8,190
6	Monday 2	5,400	× 1.17 = 6,318

(c) Adjustment of Coverage Counts

Estimating Vehicle Miles Traveled on a Network

One output of most limited-network volume studies is an estimate of the total vehicle-miles traveled (VMT) on the network during the period of interest. The estimate is done roughly by assuming that a vehicle counted on a link travels the entire length of the link. This is a reasonable assumption because some vehicles traveling only a portion of a link will be counted while others will not, depending on whether they cross the count location. Using the sample network of the previous section, the eight-hour volume results of Table 9.5, and assuming all links are 0.25 miles long, Table 9.6 illustrates the estimation of VMT. In this case, the estimate is the average eight-hour VMT for the three days of the study. It cannot be expanded into an estimate of *annual* VMT without knowing more about daily and seasonal variation patterns throughout the year.

Table 9.5: Data and Computations for a Three-Day Study Option

Time (PM)	Monday		Tuesday		Wednesday		Avg % of 8 Hours
	Count (vehs)	% of 8 Hours	Count (vehs)	% of 8 Hours	Count (vehs)	% of 8 Hours	
12–4	3,000	42.9%	3,200	42.7%	2,800	43.8%	43.1%
4–8	4,000	57.1%	4,300	57.3%	3,600	56.2%	56.9%
Total	**7,000**	**100.0%**	**7,500**	**100.0%**	**6,400**	**100.0%**	**100.0%**

(a) Control Data and Calibration of Hourly Variation Pattern

Day	8-Hour Control-Count Location A (vehs)	Adjustment Factor
Monday	7,000	6,967/7,000 = 1.00
Tuesday	7,500	6,967/7,500 = 0.93
Wednesday	6,400	6,967/6,400 = 1.09
Total	**20,900**	
Average	20,900/3 = 6,967	

(b) Calibration of Daily Variation Factors

Station	Day	Time (PM)	Count (vehs)	8-Hour Expanded Count (vehs)	8-Hour Adjusted Counts (vehs)
1	Monday	12–4	2,213	2,213/0.429 = 5,159	× 1.00 = 5,159
2	Monday	4–8	3,000	3,000/0.571 = 5,254	× 1.00 = 5,254
3	Tuesday	12–4	2,672	2,672/0.427 = 6,258	× 0.93 = 5,820
4	Tuesday	4–8	2,500	2,500/0.573 = 4,363	× 0.93 = 4,058
5	Wednesday	12–4	3,500	3,500/0.438 = 7,991	× 1.09 = 8,710
6	Wednesday	4–8	3,750	3,750/0.562 = 6,673	× 1.09 = 7,274

(c) Expansion and Adjustment of Coverage Counts

Table 9.6: Estimation of Vehicle-Miles Traveled on a Limited Network: An Example

Station	8-Hour Count (vehs)	Link Length (mi)	Link VMT (veh-miles)
A	6,967	0.25	1,741.75
1	5,159	0.25	1,289.75
2	5,254	0.25	1,313.50
3	5,820	0.25	1,455.00
4	4,058	0.25	1,014.50
5	8,710	0.25	2,177.50
6	7,274	0.25	1,818.50
Network Total			**10,810.50**

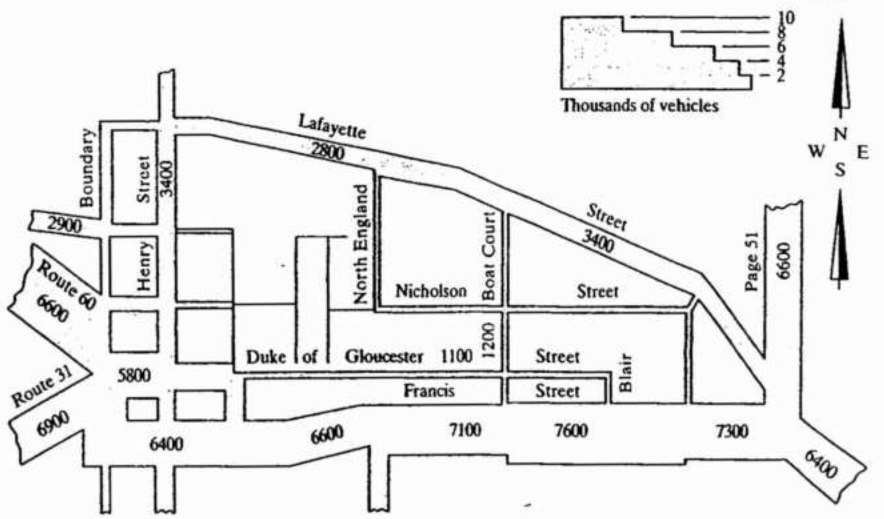


Figure 9.12: A Typical Network Flow Map

(*Source:* Used with permission of Wilbur Smith and Associates, *Traffic, Parking, and Transit – Colonial Williamsburg,* Columbia, South Carolina, 1963.)

Display of Network Volume Results

As was the case with intersection volume studies, most detailed results of a limited network study are presented in tabular form, some of which have been illustrated here. For peak hours or for daily total volumes, it is often convenient to provide a network flow map. This is similar to an intersection flow diagram in that the thickness of flow lines is proportional to the volume. An example of such a map is shown in Figure 9.12.

9.6 Statewide Counting Programs

States generally have a special interest in observing trends in AADT, shifts within the ADT pattern, and vehicle-miles traveled. These trends are used in statewide planning and for the programming of specific highway improvement projects. In recent years, there has been growing interest in person-miles traveled (PMT) and in statistics for other modes of transportation. Similar programs at the local and/or regional level are desirable for nonstate highway systems, although the cost is often prohibitive.

Following some general guidelines, as in Reference 4 for example, the state road system is divided into functional classifications. Within each classification, a pattern of control count locations and coverage count locations is established so that trends can be observed. Statewide programs are similar to limited network studies, except that the network involved is the entire state highway system and the time frame of th study is continuous (i.e., 365 days a year, every year).

These are some general principles for statewide programs

1. The objective of most statewide programs is to conduct a coverage count every year on every 2-mil segment of the state highway system, with th exception of low-volume roadways (AADT < 10 veh/day) Low-volume roadways usually compris about 50% of state system mileage and are classifie as tertiary local roads.
2. The objective of coverage counts is to produce a annual estimate of AADT for each coverage location
3. One control-count location is generally establishe for every 20 to 50 coverage-count locations, depending on the characteristics of the region served Criteria for establishing control locations are simila to those used for limited networks.
4. Control-count locations can be either *permanen counts* or *major or minor control counts,* which us representative samples. In both cases, control-coun locations must monitor and calibrate daily variatio patterns and monthly or seasonal variation pattern for the full 365-day year.
5. All coverage counts are for a minimum period of 2 to 48 hours, eliminating the need to calibrate hourl variation patterns.

Table 9.7: Calibration of Daily Variation Factors

Day	Yearly Average Volume for Day (vehs/day)	Daily Adjustment Factor (DF)
Monday	1820	1430/1820 = 0.79
Tuesday	1588	1430/1588 = 0.90
Wednesday	1406	1430/1406 = 1.02
Thursday	1300	1430/1300 = 1.10
Friday	1289	1430/1289 = 1.11
Saturday	1275	1430/1275 = 1.12
Sunday	1332	1430/1332 = 1.07
Total	**10,010**	
Estimated AADT	**1,430**	

At permanent count locations, fixed detection equip- ent with data communications technology is used to provide continuous flow of volume information. Major and minor ntrol counts are generally made using portable counters and ad tubes. Major control counts are generally made for one ek during each month of the year. Minor control counts are nerally made for one five-day (weekdays only) period in ch season.

6.1 Calibrating Daily Variation Factors

e illustrative data in Table 9.7 are obtained from a perma- nt count location. At a permanent count location, data exist r all 52 weeks of the year (i.e., for 52 Sundays, 52 Mondays, Tuesdays, etc.). (Note that in a 365-day year, one day will cur 53 times).

Daily variation factors are calibrated based on the average lumes observed during each day of the week. The base value factor calibration is the average of the seven daily averages, iich is a rough estimate of the AADT (but not exact, due to the rd piece of data for one day of the week). The factors can be tted, as illustrated in Figure 9.13, and display a clear variation ttern that can be applied to coverage count results.

Note that the sum of the seven daily adjustment factors *es not* add up to 7.00 (the actual total is 7.11). This is because the way in which the factors are defined and computed. The ily averages are in the denominator of the calibration factors. effect, the average factor is inverse to the average daily lume, so that the totals would not be expected to add to 7.00.

Daily adjustment factors can also be computed from the ults of major and/or minor control counts. In a major con- l count, there would be 12 weeks of data, one week from each month of the year. The daily averages, rather than representing 52 weeks of data, reflect 12 representative weeks of data. The calibration computations, however, are exactly the same.

9.6.2 Calibrating Monthly Variation Factors

Table 9.8 illustrates the calibration of monthly variation (MF) factors from permanent count data. The monthly factors are based on monthly ADTs that have been observed at the permanent count location. Note that the sum of the 12 monthly variation patterns is not 12.00 (the actual sum is 12.29) because the monthly ADTs are in the denominator of the calibration.

Table 9.8 is based on permanent count data, such that the monthly ADTs are directly measured. One seven-day count in each month of the year would produce similar values, except that the ADT for each month would be estimated based on a single week of data, not the entire month. This type of procedure can yield a bias when the week in which the data were collected varies from month to month. In effect, an ADT for a given month is most likely to be observed in the middle of the month (i.e., the 14th to the 16th of any month). This statement is based on the assumption that the volume trend within each month is unidirectional (i.e., volume grows throughout the month or declines throughout the month). Where a peak or low point exists within the month, this statement is not true.

Figure 9.14 illustrates a plot of 12 calibrated monthly variation factors, but one week of data is taken from each

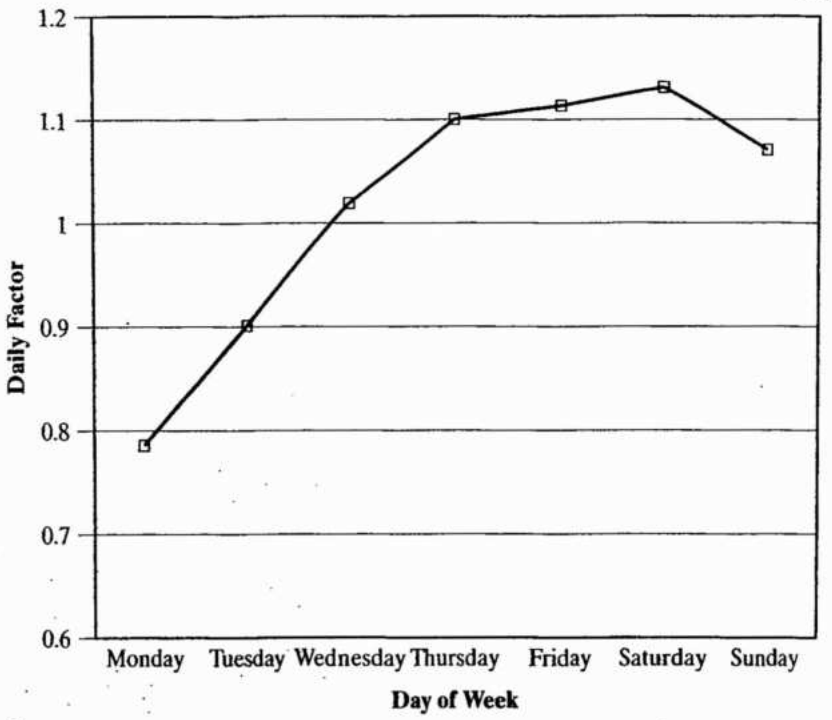


Figure 9.13: Plot of Daily Variation Factors

month. The daily variation factors are plotted against the midpoint of the week in which the data for the month were taken.

This graph may now be entered at the middle of each month (the 15th), and adjusted factors read from the vertical axis. For example, in May the computed factor was 0.93, and the plot indicates that a factor computed for the middle of that month would have resulted in a factor of 0.96. Adjusting the factors in this manner results in a more representative computation based on monthly midpoints.

Table 9.8: Calibration of Monthly Variation Factors

Month	Total Traffic (vehs)	ADT for Month (veh/day)	Monthly Factor (AADT/ADT)
January	19,840	/31 = 640	797/640 = 1.25
February	16,660	/28 = 595	797/595 = 1.34
March	21,235	/31 = 685	797/685 = 1.16
April	24,300	/30 = 810	797/810 = 0.98
May	25,885	/31 = 835	797/835 = 0.95
June	26,280	/30 = 876	797/876 = 0.91
July	27,652	/31 = 892	797/892 = 0.89
August	30,008	/31 = 968	797/968 = 0.82
September	28,620	/30 = 954	797/954 = 0.84
October	26,350	/31 = 850	797/850 = 0.94
November	22,290	/30 = 763	797/763 = 1.07
December	21,731	/31 = 701	797/701 = 1.14
Total	**290,851**	**AADT 290,851/365**	**797 veh/day**

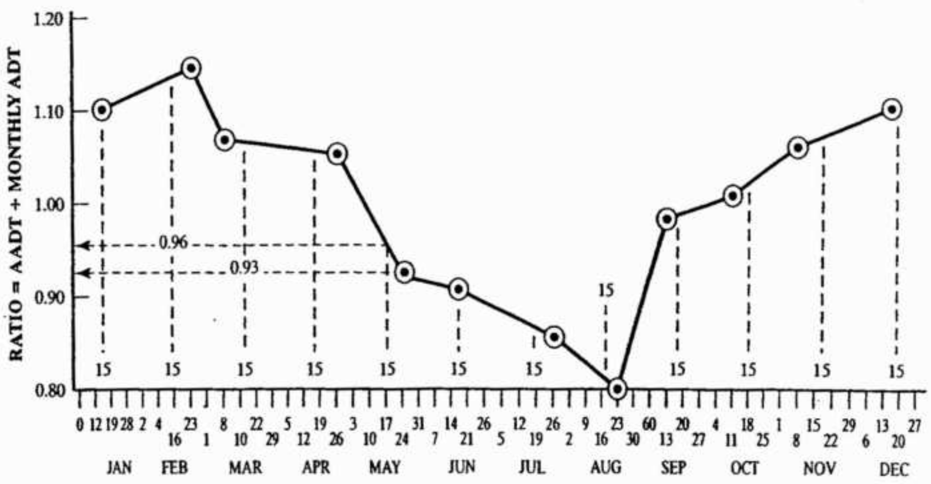


Figure 9.14: Monthly Factor Calibrated from 12 Weeks of Data

.6.3 Grouping Data from Control Count Locations

n state highway networks and systems, particularly in rural reas, it is possible for a broad region to have similar, if not he same, daily and/or monthly adjustment factors. In such egions, spatially contiguous control stations on the same lassification of highway may be combined to form a single ontrol group. The average factors for the group may then be pplied over a wide area with similar variation patterns. In eneral, a statistical standard is applied to such groupings: 'ontiguous control counts on similar highway types may be rouped if the factors at the individual locations do not differ y more than ± 0.10 from the average for the group.

Consider the example shown in Table 9.9. The daily ariation factors for four consecutive control counts on a state ighway have been calibrated as shown. It has been hypothezed that the four represent regions with similar daily variaon patterns. Average factors have, therefore, been computed r the four grouped stations.

The boldfaced factors indicate cases that violate the atistical rule for grouping (i.e., differences between these ctors and the average for the group are more than ± 0.10). his suggests that the proposed grouping is not appropriate. ne might be tempted to remove Stations 1 and 4 from the oup and combine only Stations 2 and 3. The proper techque, however, is to remove one station from the group at a ne because the resulting average factors will change. In this se, a cursory observation indicates that Station 4 does not ally display a daily variation pattern similar to the others. is station has its peak traffic (DF < 1.00) occurring during the week, whereas the other stations have their peak traffic on weekends. Thus Station 4 is deleted from the proposed grouping and new averages are computed, as illustrated in Table 9.10.

Now, all factors at individual stations are within ± 0.10 of the average for the group. This would be an appropriate grouping of control stations.

9.6.4 Using the Results

Note that groups for daily factors and groups for monthly factors do not have to be the same. It is convenient if they are, however, and it is not at all unlikely that a set of stations grouped for one type of factor would also be appropriate for the other.

Table 9.9: A Trial Grouping of Four Contiguous Control Stations with Daily Variation Factors

	DF for Station Number:				Average DF
Day	1	2	3	4	
Monday	1.05	1.00	1.06	0.92	1.01
Tuesday	1.10	1.02	1.06	**0.89**	1.02
Wednesday	1.10	1.05	1.11	0.97	1.06
Thursday	1.06	1.06	1.03	1.00	1.04
Friday	1.01	1.03	1.00	0.91	0.98
Saturday	**0.85**	0.94	0.90	**1.21**	0.98
Sunday	0.83	0.90	0.84	1.10	0.92

Note: DF = daily factor.

Table 9.10: A Second Trial Grouping of Control Stations with Daily Variation Factors

Day	DF for Station			Average (DF)
	1	2	3	
Monday	1.05	1.00	1.06	1.04
Tuesday	1.10	1.02	1.06	1.06
Wednesday	1.10	1.05	1.11	1.09
Thursday	1.06	1.06	1.03	1.05
Friday	1.01	1.03	1.00	1.01
Saturday	0.85	0.94	0.90	0.90
Sunday	0.83	0.90	0.84	0.86

Note: DF = daily factor.

The state highway agency will use its counting program to generate basic trend data throughout the state. It will also generate, for contiguous portions of each state highway classification, a set of daily and monthly variation factors that can be applied to any coverage count within the influence area of the subject control grouping. An example of the type of data that would be made available is shown in Table 9.11.

Using these tables, any coverage count for a period of 24 hours or more can be converted to an estimate of the AADT using the following relationship:

$$AADT = V_{24ij} * DF_i * MF_j \qquad (9\text{-}4)$$

where $AADT$ = average annual daily traffic, vehs/day
V_{24ij} = 24-hour volume for day i in month j, vehs
DF_i = daily adjustment factor for day i
MF_j = monthly adjustment factor for month j

Consider a coverage count taken at a location within the area represented by the factors of Table 9.11. A count of 1,000 vehicles was observed on a Tuesday in July. From Table 9.11, the daily factor (DF) for Tuesdays is 1.121, and the monthly factor (MF) for July is 0.913. Then:

$$AADT = 1{,}000 * 1.121 * 0.913 = 1{,}023 \text{ vehs/day}$$

Estimating Annual Vehicle-Miles Traveled

Given estimates of AADT for every two-mile segment of each category of roadway in the state system (excluding low-volume roads), estimates of annual vehicle-miles traveled can be assembled. For each segment, the annual vehicle-miles traveled is estimated as:

$$VMT_{365} = AADT * L * 365 \qquad (9\text{-}5)$$

where VMT_{365} = annual vehicle-miles traveled over the segment,
$AADT$ = $AADT$ for the segment, vehs/day, and
L = length of the segment, mi

For any given roadway classification or system, the segment VMTs can be summed to give a regional or statewide total. The question of the precision or accuracy of such estimates is interesting, given that none of the low-volume roads are included and that a real statewide total would need to include inputs for all non–state systems in the state. Regular counting programs at the local level are, in general, far less rigorous than state programs.

There are two other ways commonly used to estimate VMT:

- Use the number of registered vehicles with reported annual mileages, adjusting for out-of-state travel.
- Use fuel tax receipts by category of fuel (which relates to categories of vehicles), and estimate VMT using average fuel consumption ratings for different types of vehicles.

Table 9.11: Typical Daily and Monthly Variation Factors for a Contiguous Area on a State Highway System

Daily Factors (DF)		Monthly Factors (MF)			
Day	Factor	Month	Factor	Month	Factor
Monday	1.072	January	1.215	July	0.913
Tuesday	1.121	February	1.191	August	0.882
Wednesday	1.108	March	1.100	September	0.884
Thursday	1.098	April	0.992	October	0.931
Friday	1.015	May	0.949	November	1.026
Saturday	0.899	June	0.918	December	1.114
Sunday	0.789				

There is interest in improving statewide VMT estimatng procedures, and a number of significant research efforts ave been sponsored on this topic in recent years. There is lso growing interest in nationwide PMT estimates, with ppropriate modal categories.

9.7 Specialized Counting Studies

n a number of instances, simple counting of vehicles at a oint, or at a series of points, is not sufficient to provide the nformation needed. Three principal examples of specialized ounting techniques are (1) origin and destination counts, 2) cordon counts, and (3) screen-line counts.

9.7.1 Origin and Destination Counts

n many instances, normal point counts of vehicles must be upplemented with knowledge of the origins and destinations f the vehicles counted. In major regional planning applicaions, origin and destination studies involve massive homenterview efforts to establish regional travel patterns. In traffic pplications, the scope of origin and destination counts are ften more limited. Common applications include:

- Weaving-area studies
- Freeway studies
- Major activity center studies

Proper analysis of weaving-area operations requires that olume be broken down into two weaving and two nonweaving lows that are present. A total count is insufficient to evaluate erformance. In freeway corridors, it is often important to know where vehicles enter and exit the freeway. Alternative routes, or example, cannot be accurately assessed without knowing he underlying pattern of origins and destinations. At major ctivity centers (sports facilities, airports, regional shopping enters, etc.), traffic planning of access and egress also requires nowledge of where vehicles are coming from when entering he development or going to when leaving the development.

Many ITS technologies hold great promise for providng detailed information on origins and destinations. utomated toll-collection systems can provide data on where ehicles enter and leave toll facilities. Automated licenselate reading technology is used in traffic enforcement and ould be used to track vehicle paths through a traffic system. lthough these technologies continue to advance rapidly, heir use in traditional traffic data collection has been much lower due to the privacy issues that such use raises.

Historically, one of the first origin-destination count echniques was called a *lights-on study.* This method was often applied in weaving areas where vehicles arriving on one leg could be asked to turn on their lights. With the advent of daytime running lights, this methodology ~~is~~ no longer viable.

Conventional traffic origin and destination counts rely primarily on one of three approaches:

- License-plate studies
- Postcard studies
- Interview studies

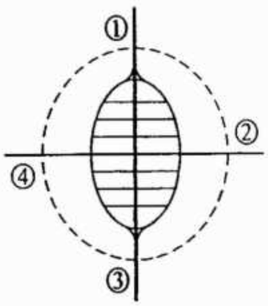
In a license-plate study, observers (or automated equipment) record the license-plate numbers as they pass designated locations. This is a common method used to track freeway entries and exits at ramps. Postcard studies involve handing out color- or otherwise coded cards as vehicles enter the system under study and collecting them as vehicles leave. In both license-plate and postcard studies, the objective is to match up vehicles at their origin and at their destination. Interview studies involve stopping vehicles (with the approval and assistance of police) and asking a short series of questions concerning their trip, where it began, where it is going, and what route will be followed.

Major activity centers are more easily approached because one end of the trip is known (everyone is at the activity center). Here, interviews are easier to conduct, and license-plate numbers of parked vehicles can be matched to home locations using data from the state Department of Motor Vehicles.

When attempting to match license-plate observations or postcards, sampling becomes a significant issue. If a sample of drivers is recorded at each entry and exit location, then the probability of finding matches is diminished considerably. If 50% of the entering vehicles at Exit 2 are observed, and 40% of the exiting vehicles at Exit 5 are observed, then the statistically expected number of matches of vehicles traveling from Exit 2 to Exit 5 would be $0.50*0.40 = 0.20$ or 20%. When such sampling techniques are used, separate counts of vehicles at all entry and exit points must be maintained to provide a means of expanding the sample data.

Consider the situation illustrated in Figure 9.15. It shows a small local downtown street network with four entry roadways and four exit roadways. Thus there are $4*4 = 16$ possible origin-destination pairs for vehicles accessing or traveling through the area. The data shown reflect both the observed origins and destinations (using license-plate samples) and the full-volume counts observed on each entry and exit leg.

If the columns and rows are totaled, the sums should be equal to the observed total volumes, assuming that a 100% sample of license plates was obtained at each location. This is obviously not the case. Thus the origin-destination volumes must be expanded to reflect the total number of vehicles counted. This can be done in two ways: (1) origin-destination cells can be expanded so that the row totals are correct (i.e., match the measured volume), or (2) origin-destination



Destination Station	Origin Station				Row Sum T_j	Vol V_j
	1	2	3	4		
1	50	8	20	17	**95**	250
2	10	65	21	10	**106**	310
3	15	12	38	15	**80**	200
4	13	14	18	42	**87**	375
Col Sum T_i	**88**	**99**	**97**	**84**		
Volume V_i	210	200	325	400		**1,135**

Figure 9.15: Data from an Origin-Destination Count Using License-Plate Matching

cells can be expanded so that the column totals are correct. Unfortunately, these two approaches will lead to two different sets of origin-destination volumes.

In practice, the average of the two approaches is adopted. This creates an iterative process because the initial adjustment will still result in column and row totals that are not the same as the measured volumes. Iteration is continued until all row and column totals are within ± 10% of the measured volumes.

The cell volumes, representing matched trips from Station i to Station j, are adjusted using factors based on column closure and row closure:

$$T_{ijN} = T_{ij(N-1)}\left(\frac{F_i + F_j}{2}\right) \tag{9-6}$$

where:

F_i = adjustment factor for origin i = V_i / T_i
F_j = adjustment factor for destination j = V_j / T_j
T_{ijN} = number of trips from station i to station j after the Nth iteration of the data (trips)
$T_{ij}(N\!-\!1)$ = number of trips from Station i to Station j after the $(N-1)$th iteration of the data (trips)
T_i = sum of matched trips from Station i (trips)
T_j = sum of matched trips to Station j (trips)
V_i = observed total volume at Station i (vehs)
V_j = observed total volume at Station j (vehs)

The actual data of Figure 9.15 serves as the 0th iteration. Each adjustment cycle results in new values of T_{ij}, T_i, T_j, F_i and F_j. The observed total volumes, of course, remain constant.

Table 9.12 shows the results of several iterations, with the final O-D counts accepted when all adjustment factors are greater than or equal to 0.90 or less than or equal to 1.10. In this case, the initial expansion of O-D counts was iterated twice to obtain the desired accuracy.

Table 9.12: Sample Expansion of Origin and Destination Data

Destination Station	Origin Station				T_j	V_j	F_j
	1	2	3	4			
1	50	8	20	17	**95**	250	2.63
2	10	65	21	10	**106**	310	2.92
3	15	12	38	15	**80**	200	2.50
4	13	14	18	42	**87**	375	4.31
T_i	**88**	**99**	**97**	**84**	**368**		
V_i	210	200	325	400		**1135**	
F_i	2.39	2.02	3.35	4.76			

(a) Field Data and Factors for Iteration 0

Table 9.12: Sample Expansion of Origin and Destination Data

Destination Station	Origin Station				T_j	V_j	F_j
	1	2	3	4			
1	125	19	60	63	**267**	250	0.94
2	27	161	66	38	**292**	310	1.06
3	37	27	111	54	**229**	200	0.87
4	44	44	69	191	**347**	375	1.08
T_i	**232**	**251**	**306**	**346**	**1135**		
V_i	210	200	325	400		**1135**	
F_i	0.90	0.80	1.06	1.16			

(b) Initial Expansion of O-D Matrix (Iteration 0)

Destination Station	Origin Station				T_j	V_j	F_j
	1	2	3	4			
1	116	16	60	66	**257**	250	0.97
2	26	150	70	43	**288**	310	1.08
3	33	23	108	55	**218**	200	0.92
4	43	42	74	213	**372**	375	1.01
T_i	**217**	**230**	**311**	**376**	**1135**		
V_i	210	200	325	400		**1135**	
F_i	0.97	0.87	1.04	1.06			

(c) First Iteration of O-D Matrix

Destination Station	Origin Station				T_j	V_j	F_j
	1	2	3	4			
1	112	15	60	67	**254**	250	0.98
2	27	145	74	46	**292**	310	1.06
3	31	20	105	55	**211**	200	0.95
4	43	39	76	221	**378**	375	0.99
T_i	**212**	**220**	**316**	**388**	**1135**		
V_i	210	200	325	400		**1135**	
F_i	0.99	0.91	1.03	1.03			

(d) Second Iteration of O-D Matrix

9.7.2 Cordon Counts

A cordon is an imaginary boundary around a study area of interest. It is generally established to define a CBD or other major activity center where the accumulation of vehicles within the area is of great importance. Cordon volume studies require counting volume at all street and highways that cross the cordon, classifying the counts by direction and by 15- to 60-minute times intervals. In establishing the cordon, several principles should be followed:

- The cordoned area must be large enough to define the full area of interest yet small enough so that accumulation estimates will be useful for parking and other traffic planning purposes.
- The cordon is established to cross all streets and highways at *midblock* locations, to avoid the complexity of establishing whether turning vehicles are entering or leaving the cordoned area.
- The cordon should be established to minimize the number of crossing points wherever possible. Natural or manufactured barriers (e.g., rivers, railroads, limited-access highways, and similar features) can be used as part of the cordon.
- Cordoned areas should have relatively uniform land use. Accumulation estimates are used to estimate street capacity and parking needs. Large cordons encompassing different land-use activities will not be focused enough for these purposes.

The accumulation of vehicles within a cordoned area is found by summarizing the total of all counts entering and leaving the area by time period. The cordon counts should begin at a time when the streets are virtually empty. Because this condition is difficult to achieve, the study should start with an estimate of vehicles already within the cordon. This can be done by circulating through the area and counting parked and circulating vehicles encountered. Off-street parking facilities can be surveyed to estimate their overnight population.

Note that an estimate of parking and standing vehicles may *not* reflect true parking demand if supply is inadequate and many circulating vehicles are merely looking for a place to park. Also, demand discouraged from entering the cordoned area due to congestion is not evaluated by this study technique.

When all entry and exit counts are summed, the accumulation of vehicles within the cordoned area during any given period may be estimated as:

$$A_i = A_{i-1} + V_{Ei} - V_{Li} \tag{9-7}$$

where: A_i = accumulation for time period i, vehs
A_{i-1} = accumulation for time period $i-1$, vehs
V_{Ei} = total volume entering the cordoned area during time period i, vehs
V_{Li} = total volume leaving the cordoned area during time period i, vehs

Table 9.13: Accumulation Computations for an Illustrative Cordon Study

Time	Vehicles Entering (vehs)	Vehicles Leaving (vehs)	Accumulation (vehs)
4:00–5:00 AM	—	—	250*
5:00–6:00 AM	100	20	250 + 100 – 20 = 330
6:00–7:00 AM	150	40	330 + 150 – 40 = 440
7:00–8:00 AM	200	40	440 + 200 – 40 = 600
8:00–9:00 AM	290	80	600 + 290 – 80 = 810
9:00–10:00 AM	350	120	810 + 350 – 120 = 1,040
10:00–11:00 AM	340	200	1,040 + 340 – 200 = 1,180
11:00–noon	350	350	1,180 + 350 – 350 = 1,180
12:00–1:00 AM	260	300	1,180 + 260 – 300 = 1,140
1:00–2:00 PM	200	380	1,140 + 200 – 380 = 960
2:00–3:00 PM	180	420	960 + 180 – 420 = 720
3:00–4:00 PM	100	350	720 + 100 – 350 = 470
4:00–5:00 PM	120	320	470 + 120 – 320 = 270

*Estimated beginning accumulation.

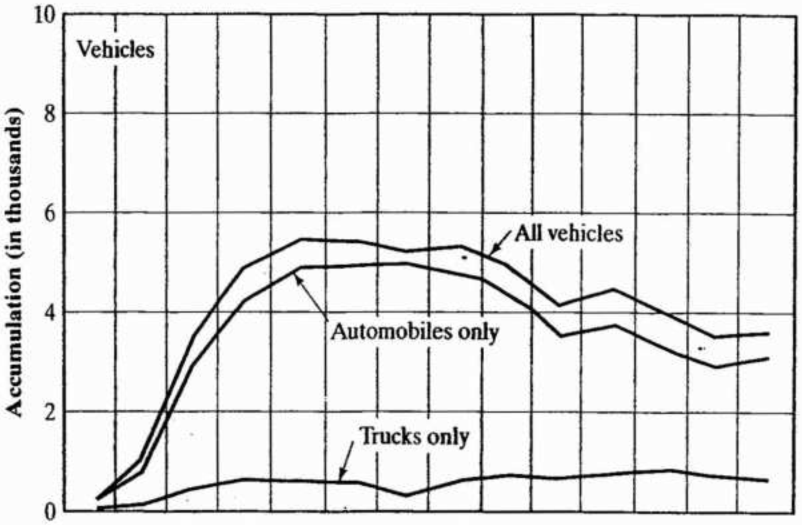
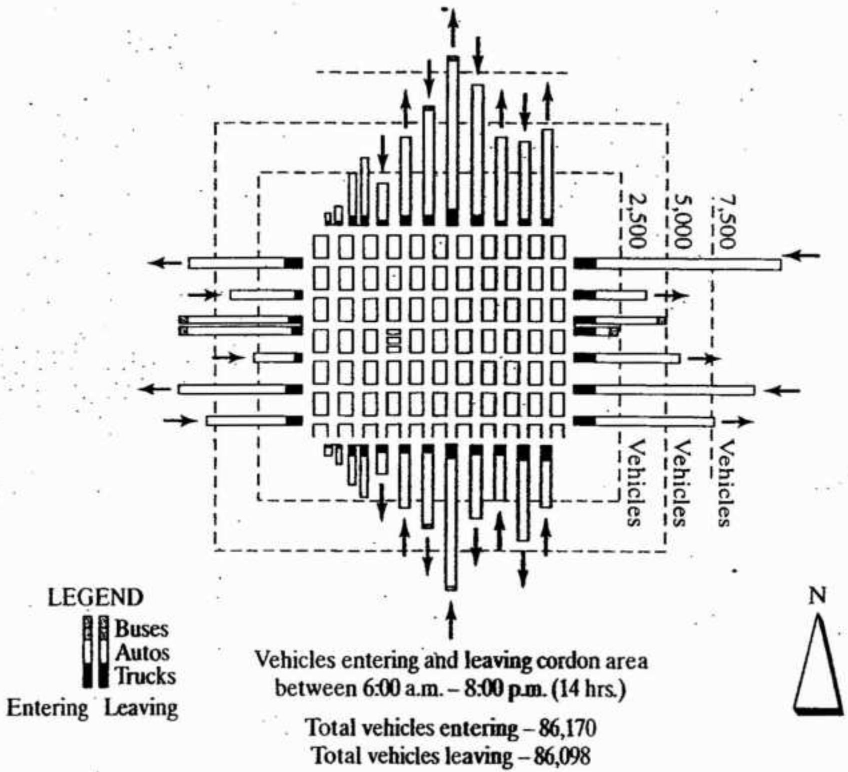


Figure 9.16: Typical Presentation of Accumulation Data

(*Source:* Used with permission of San Diego Area Transportation Study, San Diego CA, 1958.)



Vehicles entering and leaving cordon area
between 6:00 a.m. – 8:00 p.m. (14 hrs.)
Total vehicles entering – 86,170
Total vehicles leaving – 86,098

Figure 9.17: Typical Presentation of Daily Cordon Crossings

(*Source:* Used with permission of San Diego Transportation Study, San Diego CA, 1958.)

An example of a cordon volume study and the stimation of accumulation within the cordoned area shown in Table 9.13. Figure 9.16 illustrates a typical resentation of accumulation data, and Figure 9.17 illusates an interesting presentation of cordon crossing formation.

9.7.3 Screen-Line Counts

Screen-line counts and volume studies are generally conducted as part of a larger regional origin-destination study involving home interviews as the principal methodology. In such regional

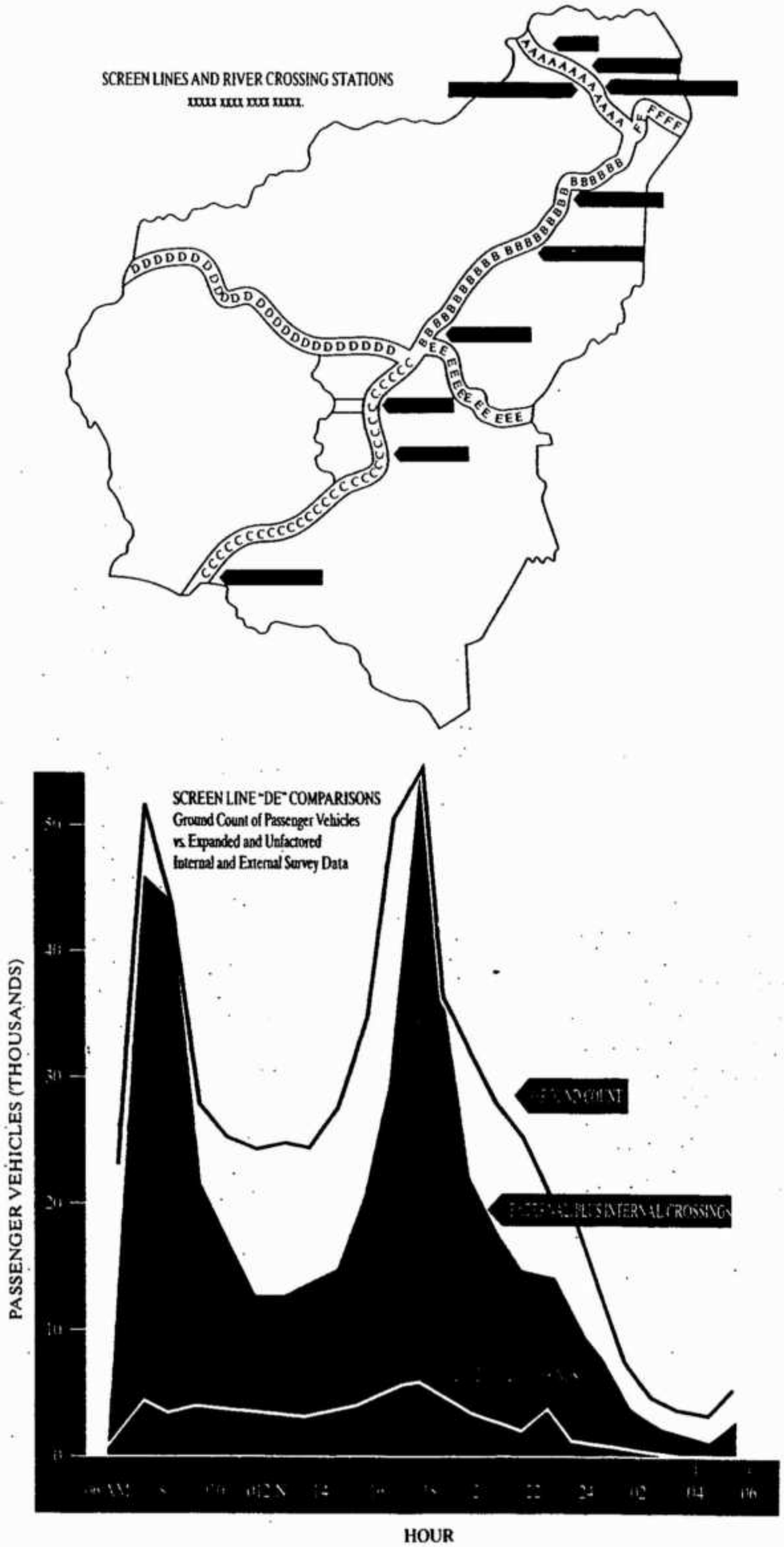


Figure 9.18: Illustration of a Screen-Line Study

(*Source:* Used with permission of Institute of Transportation Engineers, Box, P.C. and Oppenlander, J.C., *Manual of Traffic Engineering Studies*, Washington D.C., 1975, Figure 3-35, pg. 43.)

nning studies, home interview responses constitute a small but
tailed sample that is used to estimate the number of trips per
y (or some other specified time interval) between defined trans-
tation zones that have been established within the study region.

Because home interview samples are small and addi-
nal data are used to estimate trip patterns for those passing
ough the study area or having only a single trip-end within
study area, it is necessary to use some form of field obser-
tions to check on the accuracy of predicted movements.

Screen lines are convenient barriers cutting through the
dy area with only a limited number of crossing points.
vers, railroads, limited-access highways, and other features
ke good screen lines. The zone-to-zone trip estimates of a
ional study can be summed in a way that yields the predicted
mber of trips across the screen line in a defined time period.
screen-line count can then be made to observe the actual
mber of crossings. The comparison of predicted versus
served crossings provides a means by which predicted zone-
zone trips can be adjusted.

Figure 9.18 illustrates a study area for which two screen
es have been established. Predicted versus observed cross-
s are presented in graphic form. The ratio of observed to
dicted crossings provides an adjustment factor that can be
plied to all zonal trip combinations.

8 Closing Comments

e concept is simple: counting vehicles. As reviewed in this
pter, the process is not always simple; nor is the proper use of
d results to obtain the desired statistics always straightforward.
e field work of volume studies is relatively pedestrian but cru-
lly important. Volume data is one of the primary bases for all
fic engineering analysis, planning, design, and operation.

Volume data must be accurately collected. It must be
luced to understandable forms and properly analyzed to
ain the prescribed objective of the study. It must then be
sented clearly and unambiguously for use by traffic engi-
rs and others involved in the planning and engineering
cess. No geometric or traffic control design can be effec-
if it is based on incorrect data related to traffic volumes
l true demand. The importance, therefore, of performing
ume studies properly cannot be understated.

eferences

Highway Capacity Manual, 4th Edition, Transportation Research Board, National Research Council, Washington DC, 2000.

2. *Transportation and Traffic Engineering Handbook,* 2nd Edition, Prentice-Hall, Englewood Cliffs, NJ, 1982.
3. McShane, W., and Crowley, K., "Regularity of Some Detector-Observed Arterial Traffic Volume Characteristics," *Transportation Research Record 596,* Transportation Research Board, National Research Council, Washington DC, 1976.
4. *Traffic Monitoring Guide,* Federal Highway Administration, U.S. Department of Transportation, Washington DC, 1985.

Problems

9-1. A limited network counting study was conducted for the network shown here. Because only two sets of road tubes were available, the study was conducted over a period of several days, using Station A as a control location. The network is shown here.

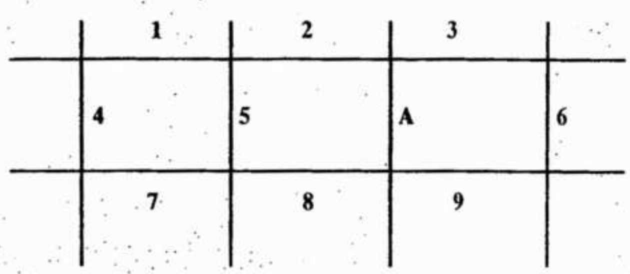


Figure 9.19: Network for Problem 9-1

Using the data from the study, shown in the tables, estimate the 12-hour volume (8 AM to 8 PM) at each station for the average day of the study.

Table 9.14: Axle Counts for Control Station A (Problem 9-1)

	Time Period		
Day	**8:00–11:45**	**12:00–3:45**	**4:00–7:45**
Monday	3,000	2,800	4,100
Tuesday	3,300	3,000	4,400
Wednesday	4,000	3,600	5,000

Table 9.15: Axle-Counts for Coverage Stations (Problem 9-1)

Station	Day	Time	Axle Count
1	Monday	8:00–11:45	1,900
2	Monday	12:00–3:45	2,600
3	Monday	4:00–7:45	1,500
4	Tuesday	8:00–11:45	3,000
5	Tuesday	12:00–3:45	3,600
6	Tuesday	4:00–7:45	4,800
7	Wednesday	8:00–11:45	3,500
8	Wednesday	12:00–3:45	3,200
9	Wednesday	4:00–7:45	4,400

Table 9.16: Sample Vehicle Classification Count (Problem 9-1)

Vehicle Class	Vehicle Count
2-axle	1,100
3-axle	130
4-axle	40
5-axle	6

9-2. The following control counts were made at state-maintained permanent count station. From the information given, calibrate the daily volume variation factors for this station:

Table 9.17: Data for Problem 9-2

Day of Week	Average Annual Volume for Day
Sunday	3,500
Monday	4,400
Tuesday	4,200
Wednesday	4,300
Thursday	3,900
Friday	4,900
Saturday	3,100

9-3. What count period would you select for a volume study at an intersection with a signal cycle length of (a) 60 seconds, (b) 90 seconds, and (c) 120 seconds?

9-4. The following control counts were made at an urban count station to develop daily and monthly variation factors. Calibrate these factors given the data shown here.

Table 9.18: 24-Hour Daily Volumes

First Week in Month of:	Day of Week						
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
January	2,000	2,200	2,250	2,000	1,800	1,500	950
April	1,900	2,080	2,110	1,890	1,750	1,400	890
July	1,700	1,850	1,900	1,710	1,580	1,150	800
October	2,100	2,270	2,300	2,050	1,800	1,550	1,010

Table 9.19: Standard Monthly Volumes

Third Week in Month of:	Average 24-Hour Count (vehs)
January	2,250
February	2,200
March	2,000
April	2,100
May	1,950
June	1,850
July	1,800
August	1,700
September	2,000
October	2,100
November	2,150
December	2,300

9-5. The four control stations shown nearby have been regrouped for the purposes of calibrating daily variation factors. Is the grouping appropriate? If not, what would an appropriate grouping be? What are the combined daily variation factors for the appropriate group(s)? The stations are located sequentially along a state route.

Table 9.20: Daily Variation Factors for Individual Stations

Station	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1	1.04	1.00	0.96	1.08	1.17	0.90	0.80
2	1.12	1.07	0.97	1.06	1.02	0.87	0.82
3	0.97	0.99	0.89	1.01	0.86	1.01	1.06
4	1.01	1.00	1.01	1.09	1.10	0.85	0.85

9-6. Estimate the annual VMT for a section of the state highway system represented by the variation factors of Table 9.11. The coverage counts shown in Table 9.21 are available for the locations within the section.

Table 9.21: Coverage Count Data

Station	Segment Length (Mi)	Coverage Count Date	24-Hour Count (vehs)
1	3.0	Wed in March	9,120
2	2.7	Tue in September	10,255
3	2.5	Fri in August	16,060
4	4.6	Sun in May	21,858
5	1.8	Thu in December	9,508
6	1.6	Fri in January	11,344

9-7. The following origin and destination results were obtained from sample license plate observations at five locations. Expand and adjust the initial trip-table results to reflect the full population of vehicles during the study period.

Table 9.22: Initial Origin and Destination Matches from Sample License-Plate Observations

Destination Station	Origin Station					Total Destination Count (vehs)
	1	**2**	**3**	**4**	**5**	
1	50	120	125	210	75	1,200
2	105	80	143	305	100	2,040
3	125	100	128	328	98	1,500
4	82	70	100	125	101	985
5	201	215	180	208	210	2,690
Total Origin Count (vehs)	**1,820**	**1,225**	**1,750**	**2,510**	**1,110**	**8,415**