Module 1: Traffic Engineering Studies

A. Introduction

Traffic engineering studies are undertaken to determine the characteristics of highway system users and their vehicles, to monitor system operation, to identify problem areas, and to assist in developing appropriate remedial action. ITE's Manual of Transportation Engineering Studies (Ref. 2) provides in-depth discussion of 18 different types of transportation engineering studies.

These notes will focus on statistical analysis and five principal types of traffic engineering studies (volume, speed, travel time and delay, parking, and pedestrian studies).

B. Basic Statistical Tools

1. Sampling. Traffic engineers are typically interested in the characteristics of a population of vehicles or people. In a spot speed study, for example, this population might consist of all northbound free-flowing vehicles on an arterial.
   a. It may not be feasible to measure the entire population for a traffic study; therefore, a sample is selected from the population and the sample data are analyzed.
   b. If the sample is large, representative, and free from bias, it reflects the population, and conclusions drawn from the sample will be fairly close to those for the population.

2. Basic statistical concepts. Assume that a representative sample of $n$ observations, with values $x_1$, $x_2$, $x_3$, ..., $x_n$, is selected from a population.
   a. Central tendency
      
      $\bar{x} = \frac{\sum x_i}{n}$

      (1) Mean or average, $\bar{x}$, is given by $\bar{x} = \frac{\sum x_i}{n}$
(2) If the $x_i$ values are rates, particularly crash rates or speeds from individual travel time runs, the previous equation will produce an incorrect answer. The true average crash rate for $n$ sections of roadway is found by dividing the total number of crashes on all $n$ sections by the total travel on all sections.

(3) The median is the 50th percentile value; by definition, half the sample observations $x_i$ are less than the median.

(4) The mode is the most frequently observed value of $x$. In traffic studies, it is often near the middle of the distribution.

(5) The mean, median, and mode all have the same units as the original data.

b. Dispersion parameters describe how widely the data are distributed.

(1) The variance, $s^2$, of sample data is given by:

$$s^2 = \frac{\sum_{i=1}^{n} x_i^2 - nx^2}{n - 1}$$

The units of the variance are the square of the units of the original data. For example, if the data were measured in units of speed (mph or km/h), the variance would be in units of speed squared [(mph)$^2$ or (km/h)$^2$].

(2) A more useful measure of dispersion is the standard deviation, $s$, the square root of the variance. It has the same units as the original data, and is calculated as:

$$s = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - nx^2}{n - 1}}$$

(3) The standard error of the mean, $s_x$, is used to determine a confidence interval for the mean of the population. It is calculated as:

$$s_x = \frac{s}{\sqrt{n}}$$

(4) The 85$^{th}$ percentile speed is the speed at or below which 85 percent of the vehicles are traveling in a spot speed study. Although it is not a true measure of dispersion, the difference between the 85$^{th}$ percentile speed and the mean speed usually provides a fair estimate of the standard deviation of the distribution.

(5) A common measure of dispersion for spot speed studies is the 10-mph (16-km/h) pace, which is characterized by both a 10-mph range and the percentage of all $x_i$ that fall within this range; the higher the percentage, the lower the dispersion.
3. **Sample sizes.** Under certain conditions, it is possible to estimate the sample size necessary to obtain sample results to a specified level of accuracy. For example, the standard error equation, \( s_e = \frac{s}{\sqrt{n}} \), can be rearranged to solve for the sample size \( n = \frac{s^2}{s_e^2} \). In a speed study, for instance, the engineer might specify 0.5 mph as an acceptable value for the \( s_e \). If previous studies found that the standard deviation on similar facilities is about 5 mph, then a sample of 100 vehicles would be sufficient. If the acceptable value of \( s_e \) is cut in half (to 0.25 mph), the sample size will quadruple to 400. (1 mph = 1.61 km/h).

## C. Volume Studies and Characteristics

The **volume** of traffic is defined as the number of vehicles (or pedestrians or other units) passing a given point on a lane or roadway during a specified period of time.

1. Volume may be distinguished by class of vehicle (classification count), direction of travel (directional count), turning movement (turning count), lane of travel (lane count), etc. The time period may vary from a year to a few minutes, depending on the nature of the location and the information required. If a time period less than one hour is used, the results are usually given as a rate of flow (an hourly representation of the number of vehicles that pass a point on a lane or roadway during a time period of less than one hour).

2. **Terminology:**
   a. **Average Annual Daily Traffic (AADT)** is the average 24-hour volume at a given location over a full 365-day year. In other words, the number of vehicles passing a point in a year divided by 365.
   b. **Average Daily Traffic (ADT)** is the average 24-hour volume recorded for some period less than a year. An ADT can be calculated for a month, a week or for two days. Most volume data used by traffic engineers are ADT counts.
   c. **Average Weekday Traffic (AWT)** is the average daily traffic between 12:01 a.m. on Monday to 12:00 midnight on Friday.
   d. **Design Hourly Volume (DHV)** a one-hour volume (or flow rate) used as the basis of design or traffic operational decisions.

3. **Counting periods**
   a. Commonly used intervals:
      - 24-hour counts covering one or more 24-hour periods
      - 16-hour counts, usually 6 am–10 pm (this period normally accounts for 90 to 95% of daily traffic)
      - 12-hour counts, usually 7 am–7 pm (this period normally accounts for about 75% of daily traffic)
      - Peak-period counts, typically 7 am–9 am and 4 pm–6 pm
      - Weekend counts, usually 6:00 p.m. Friday to 6:00 a.m. Monday
   b. **Unusual traffic conditions** (e.g., poor weather, holidays, etc.) should be avoided unless the purpose of the count is to evaluate the special traffic condition.
4. Counting programs

a. *Area-wide counting programs* are used to generate continuing estimates of traffic volumes on extensive highway systems. It is not feasible to continuously measure volumes throughout the system, so the use of sampling techniques is required. Highways are grouped into classifications according to their cyclical patterns of traffic flow. A few *permanent* count stations are established on each type of highway, and volume data are collected continuously at these locations. *Control* and *coverage* counts are used to supplement the information available from permanent count stations. *Major control* count stations may be counted for a one-week period during each month of the year. *Minor control* count stations may be counted for one week once a year. *Coverage* count stations are counted for one 24-hour period each year (or once every two to four years).

b. *Cordon counts* are made to determine the accumulation of vehicles or persons within a cordon area, such as a downtown area or trip generating land use. Each street crossing the cordon line surrounding the area is a count station, where all vehicles or persons entering and leaving the area are counted.

c. *Screenline counts* are used to measure long-term trends in volumes and direction of traffic flow. They are also used to calibrate traffic projections made with transportation planning models. Screenlines are established to divide the urban area, corridor, or highway network so that a high proportion of long, regional trips will cross one or more screenlines. Counts are made on all roadways that cross the screenline.

d. *Turning movement counts* are used for intersection design, capacity analysis, traffic signal phasing, etc. Data collected may include turning volumes, vehicle classification, and pedestrian volumes. These data are usually collected in 15-minute periods.

e. *Classification counts* are used in establishing structural and geometric design criteria, capacity analysis, determining correction factors for machine counts, etc. Vehicles are classified by type (car, truck, bus, etc.) or by number of axles.

f. *Occupancy counts* are made to determine the number of people (rather than vehicles) passing a point. These data are used for determining person accumulation within an area, proportion of people using transit facilities, average car occupancy, etc. This count requires a visual observation of vehicle occupants.

5. Volume Adjustment Factors

a. Traffic volumes vary by day of the week and by season. The accompanying Figures 1-1 and 1-2 summarize one year's data from a permanent count station on a rural state highway. Volume on this route consists of agricultural traffic and summer tourist traffic. The AADT at this station is 3419 vpd.
If a 24-hour count is taken at another point on this route on a Tuesday in April, the figures indicate that this count would be less than the AADT. It is possible to adjust for this by developing adjustment factors for different days of the week and months of the year.

1. The average daily traffic at the permanent count station on Tuesday is 3011 vpd. The expansion factor for Tuesday is given by:

\[ f_{\text{tues}} = \frac{\text{AADT}}{\text{Tuesday ADT}} = \frac{3419}{3011} = 1.14 \]

2. The ADT in April is 3078, so the expansion factor for April is:

\[ f_{\text{apr}} = \frac{\text{AADT}}{\text{April ADT}} = \frac{3419}{3078} = 1.11 \]

c. By using such daily and monthly expansion factors, a raw traffic count can be adjusted to AADT.
D. Spot Speed Studies

A spot speed study measures the individual speeds of a sample of vehicles passing a point on the roadway. If the study is conducted properly, results from this sample should represent the speed characteristics of the entire population of vehicles passing this site.

1. **Purposes**
   - Speed trends
   - Establish speed limits
   - Determine safe speeds at curves
   - Establish proper location for signs
   - Establish lengths of no-passing zones
   - Evaluate intersection sight distance
   - Before-and-after studies
   - Accident analyses
   - Geometric design
   - Research studies

2. **Study locations.** Study locations should be carefully selected to avoid introducing bias into the results of the study. Normally, points of speed change, such as curves, grades, or intersections should be avoided. Also, unusual environmental or weather conditions, heavy traffic, or recent unusual enforcement activity may result in uncharacteristic speeds. Care must also be taken to avoid detection of the speed measurement devices or personnel, which may influence vehicle speeds.

3. **Time of study.** Usually off-peak average hours are used for the speed study, when traffic is free-flowing. If a high proportion of traffic is traveling in platoons (at close headways), traffic is not free-flowing and the results of a speed study will not represent the speeds that many drivers would choose to travel at.

4. **Size and selection of a sample.** A sample size of 100 vehicles per lane is reliable under most circumstances. If a specific standard error considered acceptable, the sample size may be estimated as follows
   - Assume a value for $s$; as a general approximation, $s$ is about 3.5 to 4.5 mph on urban streets and 5 to 6 mph on freeways.
   - Specify acceptable $s^*_u$, usually less than 0.75 mph
   - Calculate:
     \[ n = \frac{s^2}{s^*_u^2} \]

Vehicles should be free-flowing and selected randomly to avoid introducing bias into the study. Some common errors in sampling speeds include:
   - Always selecting the first vehicle in platoons
   - Selecting too many trucks
   - Obtaining too large a proportion of higher speed vehicles
   - Not being alert to other events
5. **Data Collection**
   - Time vs. measured distance using machine recorders with two detectors
   - Distance vs. measured time such as video-based data collection systems
   - Radar or laser speed meter

When radar or laser devices are used to collect speed data, a **cosine error** is introduced if the angle ($\theta$) between the radar or laser beam and the direction of traffic exceeds 7 degrees on freeways (or 9 degrees on urban streets). Speeds observed in the field should be corrected to:

\[
\text{True Speed} = \frac{\text{Measured Speed}}{\cos \theta}
\]

6. **Data Analysis**

Figure 1-3 shows the results of a spot-speed study on an urban arterial. Each check mark corresponds to one vehicle traveling at speed $u_i$.

- Column (a) indicates $f_i$, the frequency of observations for any speed.
- Column (b) indicates the cumulative frequency, $\Sigma f_i$, which represents the number of vehicles traveling at or below the specific speed.
- Columns (c) and (d) show the products $f_i u_i$ and $f_i u_i^2$; these values are used to calculate the mean and standard deviation.

a. The following parameters are typically of interest

1. Mean (average) speed,

\[
\bar{u} = \frac{\sum f_i u_i}{\sum f_i}
\]

2. Median speed (50th percentile speed)

3. Standard deviation, 

\[
s = \sqrt{\frac{\sum f_i u_i^2 - n \bar{u}^2}{n - 1}}
\]

4. Standard error of the mean, 

\[
s_{\bar{u}} = \frac{s}{\sqrt{n}}
\]

b. Graphical presentations (see Figure 1-4) will show

1. Histogram shows the total number of vehicles or percentage of the sample observed traveling at a particular speed
2. Cumulative distribution curve shows the number of vehicles or percentage of the sample traveling at or less than a particular speed
3. 85th percentile speed can be read from the cumulative distribution curve; the 85th percentile speed is the speed at which 85% of the sample vehicles are traveling at or less than.
(4) 10-mph pace (lower and upper speeds and percentage in range) represents the 10-mph range of speeds that includes the largest number of sample vehicles. Normally, the pace contains about 70% of the sample, and the upper limit of the pace corresponds to the 85th percentile speed.

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Total 109 4,313 172,411

Figure 1-3. Spot Speed Study Data
Research has concluded that comfortable speeds on curves are indicated by ball-bank readings of up to $14^\circ$ for speeds of 20 mph (30 km/h) or less, $12^\circ$ for speeds between 25 and 30 mph (40 to 50 km/h), and $10^\circ$ for speeds of 35 mph (55 km/h) and higher. To determine the advisory speed for a curve, the vehicle is driven at a constant speed through the curve at successively higher speeds until the highest speed is reached without exceeding the desired maximum ball-bank indicator reading. Figure 1-6 shows a sample data collection form.

![Ball Bank Indicator](image)

**Figure 1-5. Ball Bank Indicator**

<table>
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<th>CURVE ADVISORY SPEED FIELD FORM</th>
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<td>Direction: _____________________</td>
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<tr>
<td>Date: __________________________</td>
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<tr>
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</tr>
<tr>
<td>Recorder: ______________________</td>
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<td>Posted Speed Limit: 40 mph ______</td>
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<th>Recommended Maximum Readings at Indicated Speeds</th>
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**Figure 1-6. Ball Bank Indicator Curve Advisory Speed Field Form**
CHAPTER 4C. TRAFFIC CONTROL SIGNAL NEEDS STUDIES

Section 4C.01 Studies and Factors for Justifying Traffic Control Signals

Standard:

An engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.

The investigation of the need for a traffic control signal shall include an analysis of the applicable factors contained in the following traffic signal warrants and other factors related to existing operation and safety at the study location:

- Warrant 1, Eight-Hour Vehicular Volume.
- Warrant 2, Four-Hour Vehicular Volume.
- Warrant 3, Peak Hour.
- Warrant 4, Pedestrian Volume.
- Warrant 5, School Crossing.
- Warrant 6, Coordinated Signal System.
- Warrant 7, Crash Experience.
- Warrant 8, Roadway Network.

The satisfaction of one or more traffic signal warrants shall not in itself require the installation of a traffic control signal.

Support:

Sections 8D.07 and 10D.05 contain information regarding the use of traffic control signals instead of gates and/or flashing light signals at highway-railroad grade crossings and highway-light rail transit grade crossings, respectively.

Guidance:

A traffic control signal should not be installed unless one or more of the factors described in this Chapter are met.

A traffic control signal should not be installed unless an engineering analysis indicates that installing a traffic control signal will potentially improve the safety and/or operation of the intersection.

A traffic control signal should not be installed if it will seriously disrupt progressive traffic flow.

The study should consider the effects of the right-turn vehicles from the minor-street approaches. Engineering judgment should be used to determine what, if any, portion of the right-turn traffic is subtracted from the minor-street traffic count when evaluating the count against the above signal warrants.

Engineering judgment should also be used in applying various traffic signal warrants to cases where approaches consist of one lane plus one left-turn or right-turn lane. The site-specific traffic characteristics dictate whether an approach should be considered as one lane or two lanes. For example, for an approach with one lane for through and right-turning traffic plus a left-turn lane, engineering judgment could indicate that it should be considered a one-lane approach if the traffic using the left-turn lane is minor. In such a case, the total traffic volume approaching the intersection should be applied against the signal warrants as a one-lane approach. The approach should be considered two lanes if approximately half of the traffic on the approach turns left and the left-turn lane is of sufficient length to accommodate all left-turn vehicles.

Similar engineering judgment and rationale should be applied to a street approach with one lane plus a right-turn lane. In this case, the degree of conflict of minor-street right-turn traffic with traffic on the major street should be considered. Thus, right-turn traffic should not be included in the minor-street volume if the movement enters the major street with minimal conflict. The approach should be evaluated as a one-lane approach with only the traffic volume in the through/left-turn lane considered.

At a location that is under development or construction and where it is not possible to obtain a traffic count that would represent future traffic conditions, hourly volumes should be estimated as part of an engineering study for comparison with traffic signal warrants. Except for locations where the engineering study uses the satisfaction of Warrant 8 to justify a signal, a traffic control signal installed under projected conditions should have an engineering study done within 1 year of putting the signal into stop-and-go operation to determine if the signal is justified. If not justified, the signal should be taken out of stop-and-go operation or removed.

For signal warrant analysis, a location with a wide median, even if the median width is greater than 9 m (30 ft), should be considered as one intersection.
Option:
At an intersection with a high volume of left-turn traffic from the major street, the signal warrant analysis may be performed in a manner that considers the higher of the major-street left-turn volumes as the "minor street" volume and the corresponding single direction of opposing traffic on the major street as the "major-street" volume.

For signal warrant analysis, bicyclists may be counted as either vehicles or pedestrians.

Support:
When performing a signal warrant analysis, bicyclists riding in the street with other vehicular traffic are usually counted as vehicles and bicyclists who are clearly using pedestrian facilities are usually counted as pedestrians.

Option:
The analysis may consider the effects of right turn vehicles and the associated permitted movement on a "Red" signal indication after a stop, under assumed traffic signal operation, from all the approaches. Engineering judgment may be used to determine what, if any, portion of the right turn traffic is subtracted from the approach traffic count when evaluating the vehicular traffic count against the traffic signal warrant values.

Satisfaction of a single traffic signal warrant, with a documented engineering study/review, can be justification for the installation of a traffic signal at a specific location.

Engineering study data may include the following:
A. The number of vehicles entering the intersection in each hour from each approach during 12 hours of an average day. It is desirable that the hours selected contain the greatest percentage of the 24-hour traffic volume.
B. Vehicular volumes for each traffic movement from each approach, which may be classified by vehicle type (trucks or passenger cars, and, in some locations, school buses), during each 15-minute period of the 2 hours in the morning and 2 hours in the afternoon during which total traffic entering the intersection is greatest.
C. Pedestrian volume counts on each crosswalk during the hours of highest pedestrian volume. Where young, elderly, and/or persons with physical or visual disabilities need special consideration, the pedestrians and their crossing times may be classified by general observation.
D. Information about nearby facilities and activity centers that serve the young, elderly, and/or persons with disabilities, including requests from persons with disabilities for accessible crossing improvements at the location under study. These persons might not be adequately reflected in the pedestrian volume count if the absence of a signal restrains their mobility.
E. The posted or statutory speed limit or the 85th-percentile speed on the uncontrolled approaches to the location.
F. A condition diagram showing details of the physical layout, including such features as intersection geometrics, channelization, grades, sight-distance restrictions, transit stops and routes, parking conditions, pavement markings, roadway lighting, driveways, nearby railroad crossings, distance to nearest traffic control signals, utility poles and fixtures, and adjacent land use.
G. A collision diagram showing crash experience by type, location, direction of movement, severity, weather, time of day, date, and day of week for a desirable period of three or more years, if the information is available.

The following data, which are desirable for a more precise understanding of the operation of the intersection, may be obtained:
A. Vehicle-hours of stopped time delay determined separately for each approach.
B. The number and distribution of acceptable gaps in vehicular traffic on the major street for entrance from the minor street.
C. The posted or, if not posted, the statutory speed limit or the 85th-percentile speed on controlled approaches at a point near to the intersection but unaffected by the control.
D. Pedestrian delay time for at least two 30-minute peak pedestrian delay periods of an average weekday or like periods of a Saturday or Sunday.
E. Queue length on stop-controlled approaches.

Section 4C.02 Warrant I, Eight-Hour Vehicular Volume
Support:
The Minimum Vehicular Volume, Condition A, or A1, is intended for application at locations where a large volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

The Interruption of Continuous Traffic, Condition B, or B1, is intended for application at locations where Condition A is not satisfied and where the traffic volume on a major street is so heavy that traffic on a minor
intersecting street suffers excessive delay or conflict in entering or crossing the major street.

It is intended that Warrant 1 be treated as a single warrant. If Condition A, or A1, is satisfied, then the criteria for Warrant 1 is satisfied and Condition B and the combination of Conditions A and B are not needed. Similarly, if Condition B, or B1, is satisfied, then the criteria for Warrant 1 is satisfied and the combination of Conditions A and B is not needed.

Standard:

The need for a traffic control signal shall be considered if an engineering study finds that one of the following conditions exist for each of any 8 hours of an average day:

A. The vehicles per hour given in both of the 100 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; or

B. The vehicles per hour given in both of the 100 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

In applying each condition the major-street and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of these 8 hours.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 70 km/h or exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 70 percent columns in Table 4C-1 may be used in place of the 100 percent columns.

Guidance:

The combination of Conditions A and B is intended for application at locations where Condition A is not satisfied and Condition B is not satisfied and should be applied only after consideration of other alternatives that could cause less delay and inconvenience to traffic.

Standard:

The need for a traffic control signal shall be considered if an engineering study finds that both of the following conditions exist for each of any 8 hours of an average day:

A. The vehicles per hour given in both of the 80 percent columns of Condition A in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection; and

B. The vehicles per hour given in both of the 80 percent columns of Condition B in Table 4C-1 exist on the major-street and the higher-volume minor-street approaches, respectively, to the intersection.

These major-street and minor-street volumes shall be for the same 8 hours for each condition; however, the 8 hours satisfied in Condition A shall not be required to be the same 8 hours satisfied in Condition B. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Option:

When comparing vehicular volume of both approaches of the major street against the volume of the side street approaches, each side street approach may independently be evaluated against the criteria listed in Condition A and Condition B of TABLE 4C-1.

Temporary traffic signals may be installed at new intersections on predicted hourly vehicular volumes, providing the predicted volumes meet the prescribed minimum vehicular volume levels as noted in Condition A or Condition B of TABLE 4C-1.

Temporary traffic signals may be installed at new intersections on predicted average daily traffic volumes, providing the predicted volumes meet prescribed minimum levels as noted in Condition A1 or Condition B1 of TABLE 4C-2. The temporary traffic signals may be placed in signal operation until proper traffic data and experience can be obtained. No downward adjustments are to be made to the ADT required volumes.

The basis for use of TABLE 4C-2 are:

1. The traffic volumes used shall be assigned current volumes.
2. Conditions A1 or B1 lists the minimum Average Daily Traffic volumes which may justify consideration of signalization, and which are considered to be equivalent to the hourly traffic volume stipulations denoted by Condition A and Condition B respectively.
### Table 4C-1. Warrant 1, Eight-Hour Vehicular Volume

#### Condition A—Minimum Vehicular Volume

<table>
<thead>
<tr>
<th>Number of lanes for moving traffic on each approach</th>
<th>Vehicles per hour on major street (total of both approaches)</th>
<th>Vehicles per hour on higher-volume minor-street approach (one direction only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Street</strong></td>
<td><strong>Minor Street</strong></td>
<td><strong>100%</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>2 or more...</td>
<td>1</td>
<td>600</td>
</tr>
<tr>
<td>2 or more...</td>
<td>2 or more...</td>
<td>600</td>
</tr>
<tr>
<td>1</td>
<td>2 or more...</td>
<td>500</td>
</tr>
</tbody>
</table>

#### Condition B— Interruption of Continuous Traffic

<table>
<thead>
<tr>
<th>Number of lanes for moving traffic on each approach</th>
<th>Vehicles per hour on major street (total of both approaches)</th>
<th>Vehicles per hour on higher-volume minor-street approach (one direction only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Street</strong></td>
<td><strong>Minor Street</strong></td>
<td><strong>100%</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>750</td>
</tr>
<tr>
<td>2 or more...</td>
<td>1</td>
<td>900</td>
</tr>
<tr>
<td>2 or more...</td>
<td>2 or more...</td>
<td>900</td>
</tr>
<tr>
<td>1</td>
<td>2 or more...</td>
<td>750</td>
</tr>
</tbody>
</table>

---

*Basic minimum hourly volume.  
*Used for combination of Conditions A and B after consideration of other remedial measures.  
*May be used when the major-street speed exceeds 70 km/h or exceeds 40 mph or in an isolated community with a population of less than 10,000.  
*May be used for combination of Conditions A and B after consideration of other remedial measures when the major street speed exceeds 70 km/h or exceeds 40 mph or in an isolated community with a population of less than 10,000.

### Table 4C-2, Eight-Hour Vehicular Volume (ADT Equivalent)

#### Condition A1 - Minimum Vehicular Volume (ADT Equivalent)

<table>
<thead>
<tr>
<th>Number of lanes on each approach</th>
<th>Equivalent Average Daily Traffic Volumes Approaching From Both Directions On:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Street</strong></td>
<td><strong>Minor Street</strong></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
</tr>
<tr>
<td>2 or more</td>
<td>2 or more</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
</tr>
</tbody>
</table>

#### Condition B1 - Interruption of Continuous Traffic (ADT Equivalent)

<table>
<thead>
<tr>
<th>Number of lanes on each approach</th>
<th>Equivalent Average Daily Traffic Volumes Approaching From Both Directions On:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Street</strong></td>
<td><strong>Minor Street</strong></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
</tr>
<tr>
<td>2 or more</td>
<td>2 or more</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
</tr>
</tbody>
</table>
3. Surveillance should be maintained on the temporary traffic signal to assure that the signal operation is not creating any undue problems.

4. An engineering study should be conducted, normally, after six months of operation and before one year of operation as a temporary traffic signal control, to determine if the traffic signal is needed and should become a permanent installation.

5. If the temporary traffic signal is not justified by an engineering study, it may be removed immediately and the appropriate traffic control devices, commensurate to justification revealed by the engineering study, may be installed.

6. If the engineering study indicates that the traffic signal is justified, it shall remain in place and have the status of a permanent traffic signal installation.

Temporary traffic signals installed under this procedure must conform to the design requirements for traffic signals as stipulated in this manual.

Temporary traffic signals may become permanent traffic signals only after the completion of a traffic engineering investigation that verifies that permanent traffic signals are justified.

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 70 km/h or exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 56 percent columns in Table 4C-1 may be used in place of the 80 percent columns.

Section 4C.03 Warrant 2, Four-Hour Vehicular Volume

Support:

The Four-Hour Vehicular Volume signal warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic control signal.

Standard:

The need for a traffic control signal shall be considered if an engineering study finds that, for each of any 4 hours of an average day, the plotted points representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) all fall above the applicable curve in Figure 4C-1 for the existing combination of approach lanes. On the minor street, the higher volume shall not be required to be on the same approach during each of these 4 hours.

Option:

When comparing vehicular volumes depicted in Figure 4C-1, the appropriate equations, as listed in Table 4C-3, may be used.

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 70 km/h or exceeds 40 mph or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4C-2 may be used in place of Figure 4C-1.

When comparing vehicular volumes depicted in Figure 4C-2, the appropriate equations, as listed in Table 4C-4, may be used.
**Figure 4C-1. Warrant 2, Four-Hour Vehicular Volume**

*Note: 115 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 80 vph applies as the lower threshold volume for a minor-street approach with one lane.

**Figure 4C-2. Warrant 2, Four-Hour Vehicular Volume (70 % Factor)**

(Community less than 10,000 population or above 70 km/h or above 40 mph on major street)

*Note: 80 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 60 vph applies as the lower threshold volume for a minor-street approach with one lane.
Table 4C-3. Warrant 2, Four-Hour Vehicular Volume
Mathematical Equation Equivalency to Figure 4C-1

<table>
<thead>
<tr>
<th>Minor Street(Y)</th>
<th>Major Street(X)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 or more</td>
<td>2 or more</td>
<td>If X &gt;= 1295, Y = 1.15 or Y = 879.232228 - 1.011380233X +0.0003253082X^2</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
<td>If X &gt;= 1118, Y = 1.15 or Y = 651.50622395 - 0.7483745392X +0.000240228X^2</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
<td>If X &gt;= 1340, Y = 80 or Y = 651.50622395 - 0.7483745392X +0.000240228X^2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>If X &gt;= 1092, Y = 80 or Y = 550.22697349 - 0.6996410769X +0.0002462697X^2</td>
</tr>
</tbody>
</table>

Table 4C-4. Warrant 2, Four-Hour Vehicular Volume (70% Factor)
Mathematical Equation Equivalency to Figure 4C-2

<table>
<thead>
<tr>
<th>Minor Street(Y)</th>
<th>Major Street(X)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 or more</td>
<td>2 or more</td>
<td>If X &gt;= 890, Y = 80 or Y = 613.777772474 - 0.9893678281X +0.0004377428X^2</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
<td>If X &gt;= 797, Y = 80 or Y = 460.53837044 - 0.7635806818X +0.0003591016X^2</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
<td>If X &gt;= 940, Y = 60 or Y = 460.53837044 - 0.7635806818X +0.0003591016X^2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>If X &gt;= 782, Y = 60 or Y = 377.22710663 - 0.6793503652X +0.0003501046X^2</td>
</tr>
</tbody>
</table>

When comparing vehicular volume of both approaches of the major street against the volume of the side street approaches, each side street approach may independently be evaluated against the criteria listed in Figure 4C-1, 4C-2, Table 4C-3 or Table 4C-4, as appropriate.

Section 4C.04 Warrant 3, Peak Hour

Support:

The Peak Hour signal warrant is intended for use at a location where traffic conditions are such that for a minimum of 1 hour of an average day, the minor-street traffic suffers undue delay when entering or crossing the major street.

Standard:

This signal warrant shall be applied only in unusual cases, such as office complexes, manufacturing plants, industrial complexes, or high-occupancy vehicle facilities that attract or discharge large numbers of vehicles over a short time.

The need for a traffic control signal shall be considered if an engineering study finds that the criteria in either of the following two categories are met:

A. If all three of the following conditions exist for the same 1 hour (any four consecutive 15-minute periods) of an average day:
   1. The total stopped time delay experienced, or estimated by the method described in the Highway Capacity Manual for unsignalized intersections, by the traffic on one minor-street approach (one direction only) controlled by a STOP sign equals or exceeds: 4 vehicle-hours for a one-lane approach; or 5 vehicle-hours for a two-lane approach, and
   2. The volume on the same minor-street approach (one direction only) equals or exceeds 100 vehicles per hour for one moving lane of traffic or 150 vehicles per hour for two moving lanes, and
   3. The total entering volume serviced during the hour equals or exceeds 650 vehicles per hour for intersections with three approaches or 800 vehicles per hour for intersections with four or more approaches.
B. The plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the higher-volume minor-street approach (one direction only) for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 4C-3 for the existing combination of approach lanes.

Option:
When comparing vehicular volumes depicted in Figure 4C-3, the appropriate equations, as listed in Table 4C-5, may be used.

If the posted or statutory speed limit or the 85th percentile speed on the major street exceeds 70 km/h or exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, Figure 4C-4, or TABLE 4C-6, may be used in place of Figure 4C-3, or TABLE 4C-5, to satisfy the criteria in the second category of the Standard.

Section 4C.05 Warrant 4, Pedestrian Volume
Support:
The Pedestrian Volume signal warrant is intended for application where the traffic volume on a major street is so heavy that pedestrians experience excessive delay in crossing the major street.

Standard:
The need for a traffic control signal at an intersection or midblock crossing shall be considered if an engineering study finds that both of the following criteria are met:

A. The pedestrian volume crossing the major street at an intersection or midblock location during an average day is 100 or more for each of any 4 hours or 190 or more during any 1 hour; and

B. There are fewer than 60 gaps per hour in the traffic stream of adequate length to allow pedestrians to cross during the same period when the pedestrian volume criterion is satisfied. Where there is a divided street having a median of sufficient width for pedestrians to wait, the requirement applies separately to each direction of vehicular traffic.

The Pedestrian Volume signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 90 m (300 ft), unless the proposed traffic control signal will not restrict the progressive movement of traffic.

If this warrant is met and a traffic control signal is justified by an engineering study, the traffic control signal shall be equipped with pedestrian signal heads conforming to requirements set forth in Chapter 4E.

Guidance:
If this warrant is met and a traffic control signal is justified by an engineering study, then:

A. If at an intersection, the traffic control signal should include pedestrian detectors if semi-actuated.

B. If at a nonintersection crossing, the traffic control signal should be pedestrian-actuated, parking and other sight obstructions should be prohibited for 30 m (100 ft) in advance of and 6.1 m (20 ft) beyond the crosswalk, and the installation should include suitable standard signs and pavement markings.

C. Furthermore, if installed within a signal system, the traffic control signal should be coordinated.

Option:
The criterion for the pedestrian volume crossing the major roadway may be reduced as much as 50 percent if the average crossing speed of pedestrians is less than 1.2 m/sec (4 ft/sec).

A traffic control signal may not be needed at the study location if adjacent coordinated traffic control signals consistently provide gaps of adequate length for pedestrians to cross the street, even if the rate of gap occurrence is less than one per minute.

Section 4C.06 Warrant 5, School Crossing
Support:
The School Crossing signal warrant is intended for application where the fact that school children cross the major street is the principal reason to consider installing a traffic control signal.
**Figure 4C-3. Warrant 3, Peak Hour**

MAJOR STREET—TOTAL OF BOTH APPROACHES—VEHICLES PER HOUR (VPH)

*Note: 150 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 100 vph applies as the lower threshold volume for a minor-street approach with one lane.*

**Figure 4C-4. Warrant 3, Peak Hour (70% Factor)**

(COMMUNITY LESS THAN 10,000 POPULATION OR ABOVE 70 km/h OR ABOVE 40 mph ON MAJOR STREET)

MAJOR STREET—TOTAL OF BOTH APPROACHES—VEHICLES PER HOUR (VPH)

*Note: 100 vph applies as the lower threshold volume for a minor-street approach with two or more lanes and 75 vph applies as the lower threshold volume for a minor-street approach with one lane.*
Table 4C-5. Warrant 3, Peak Hour
Mathematical Equation Equivalency to Figure 4C-3

<table>
<thead>
<tr>
<th>Minor Street(Y)</th>
<th>Major Street(X)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 or more</td>
<td>2 or more</td>
<td>If X =&gt; 1672, Y = 150 or Y = 1060.5405451 - 0.889969286X + 0.0002059999X^2</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
<td>If X =&gt; 1461, Y = 150 or Y = 837.59424427 - 0.7219511908X + 0.0001720248X^2</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
<td>If X =&gt; 1759, Y = 100 or Y = 837.59424427 - 0.7219511908X + 0.0001720248X^2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>If X =&gt; 1516, Y = 100 or Y = 745.652000052 - 0.7548866636X + 0.000217033X^2</td>
</tr>
</tbody>
</table>

Table 4C-6. Warrant 3, Peak Hour (70% Factor)
Mathematical Equation Equivalency to Figure 4C-4

<table>
<thead>
<tr>
<th>Minor Street(Y)</th>
<th>Major Street(X)</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 or more</td>
<td>2 or more</td>
<td>If X =&gt; 1183, Y = 100 or Y = 771.842673 - 0.9817221615X + 0.0002498922X^2</td>
</tr>
<tr>
<td>2 or more</td>
<td>1</td>
<td>If X =&gt; 1040, Y = 100 or Y = 593.38729059 - 0.7471500045X + 0.000262383X^2</td>
</tr>
<tr>
<td>1</td>
<td>2 or more</td>
<td>If X =&gt; 1196, Y = 75 or Y = 593.38729059 - 0.7471500045X + 0.000262383X^2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>If X =&gt; 1054, Y = 75 or Y = 520.01150224 - 0.7647561999X + 0.0003250549X^2</td>
</tr>
</tbody>
</table>

Standard:

The need for a traffic control signal shall be considered when an engineering study of the frequency and adequacy of gaps in the vehicular traffic stream as related to the number and size of groups of school children at an established school crossing across the major street shows that the number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period (see Section 7A.03) and there are a minimum of 20 students during the highest crossing hour.

Before a decision is made to install a traffic control signal, consideration shall be given to the implementation of other remedial measures, such as warning signs and flashers, school speed zones, school crossing guards, or a grade-separated crossing.

The School Crossing signal warrant shall not be applied at locations where the distance to the nearest traffic control signal along the major street is less than 90 m (300 ft), unless the proposed traffic control signal will not restrict the progressive movement of traffic.

Guidance:

If this warrant is met and a traffic control signal is justified by an engineering study, then:

A. If at an intersection, the traffic control signal should include pedestrian detectors if actuated or semi-actuated.

B. If at a nonintersection crossing, the traffic control signal should be pedestrian-actuated, parking and other sight obstructions should be prohibited for 30 m (100 ft) in advance of and 6.1 m (20 ft) beyond the crosswalk, and the installation should include suitable standard signs and pavement markings.

C. Furthermore, if installed within a signal system, the traffic control signal should be coordinated.

Option:

As an alternate to obtaining the actual number of available gaps, of adequate length, to permit for the safe crossing of the street by school children, actual vehicular volumes traversing the school crosswalk can be compared to the conditions denoted in Table 4C-7 for the purpose of determining the potential need for a traffic signal.
Table 4C-7. Vehicular Volume Equivalency For Insufficient Gaps In Vehicular Flow

<table>
<thead>
<tr>
<th>Average Number of Children Per Minute</th>
<th>Width of Street Vehicular Volume (v.p.h.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30'</td>
</tr>
<tr>
<td>1 - 5</td>
<td>645</td>
</tr>
<tr>
<td>6 - 10</td>
<td>620</td>
</tr>
<tr>
<td>11 - 15</td>
<td>590</td>
</tr>
<tr>
<td>16 - 20</td>
<td>565</td>
</tr>
<tr>
<td>21 - 25</td>
<td>540</td>
</tr>
<tr>
<td>26 - 30</td>
<td>510</td>
</tr>
<tr>
<td>31 - 35</td>
<td>485</td>
</tr>
</tbody>
</table>

**Section 4C.07 Warrant 6, Coordinated Signal System**

Support:

Progressive movement in a coordinated signal system sometimes necessitates installing traffic control signals at intersections where they would not otherwise be needed in order to maintain proper platooning of vehicles.

Standard:

The need for a traffic control signal shall be considered if an engineering study finds that one of the following criteria is met:

A. On a one-way street or a street that has traffic predominantly in one direction, the adjacent traffic control signals are so far apart that they do not provide the necessary degree of vehicular platooning.

B. On a two-way street, adjacent traffic control signals do not provide the necessary degree of platooning and the proposed and adjacent traffic control signals will collectively provide a progressive operation.

Guidance:

The Coordinated Signal System signal warrant should not be applied where the resultant spacing of traffic control signals would be less than 300 m (1,000 ft) or where the resultant traffic signal would be the first signal in the signal system.

**Section 4C.08 Warrant 7, Crash Experience**

Support:

The Crash Experience signal warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal.

Standard:

The need for a traffic control signal shall be considered if an engineering study finds that all of the following conditions are met:

A. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency; and

B. Five or more reported crashes, of types susceptible to correction by a traffic control signal, have occurred within a 12-month period, each crash involving personal injury or property damage apparently exceeding the applicable requirements for a reportable crash; and

C. For each of any 8 hours of an average day, the vehicles per hour (vph) given in both of the 80 percent columns of Condition A in Table 4C-1 (see Section 4C.02), or the vph in both of the 80 percent columns of Condition B in Table 4C-1 exists on the major-street and the higher-volume minor-street approach, respectively, to the intersection, or the volume of pedestrian traffic is not less than 80 percent of the requirements specified in the Pedestrian Volume warrant. These majorstreeet and minor-street volumes shall be for the same 8 hours. On the minor street, the higher volume shall not be required to be on the same approach during each of the 8 hours.

Option:

If the posted or statutory speed limit or the 85th-percentile speed on the major street exceeds 70 km/h or exceeds 40 mph, or if the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the traffic volumes in the 56 percent columns in Table 4C-1 may be used in place of the 80 percent columns.
Section 4C.09 Warrant 8, Roadway Network

Support:
Installing a traffic control signal at some intersections might be justified to encourage concentration and organization of traffic flow on a roadway network.

Standard:
The need for a traffic control signal shall be considered if an engineering study finds that the common intersection of two or more major routes meets one or both of the following criteria:

A. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 vehicles per hour during the peak hour of a typical weekday and has 5-year projected traffic volumes, based on an engineering study, that meet one or more of Warrants 1, 2, and 3 during an average weekday; or

B. The intersection has a total existing or immediately projected entering volume of at least 1,000 vehicles per hour for each of any 5 hours of a nonnormal business day (Saturday or Sunday).

A major route as used in this signal warrant shall have one or more of the following characteristics:
A. It is part of the street or highway system that serves as the principal roadway network for through traffic flow; or
B. It includes rural or suburban highways which are adjacent to, entering, or traversing a City; or
C. It appears as a major route on an official plan, such as a major street plan in an urban area traffic and transportation study.