THE HIERARCHY OF INTERSECTION CONTROL

Introduction

The most complex individual locations within any street and highway system are at-grade intersections. At a typical intersection of two two-way streets, there are 12 legal vehicular movements
(Left turn, though, and right turn from four approaches) and four legal pedestrian crossing movements. As indicated in Figure 1, these movements create many potential conflicts where vehicles and/or pedestrian paths may try to occupy the same physical space at the same time.
As illustrated, there are a total of 16 potential vehicular crossing conflicts:

- four between through movements from the two streets,
- four between left-turning movements from the two streets, and
- Eight between left-turning movements and through movements from the two streets.

In addition, there are eight vehicular merge conflicts as right- and left turning vehicles merge into a through flow at the completion of their desired maneuver. Pedestrians add additional potential conflicts to the mix.
The critical task of the traffic engineer is to control and manage these conflicts in a manner that ensures safety and provides for efficient movement through the intersection for both motorists and pedestrians.

Three basic levels of control can be implemented at an intersection:

- Level I-Basic rules of the road.
- Level II-Direct assignment of right-of-way using YIELD or STOP signs.
- Level III- Traffic signalization.

There are variations within each level of control as well. The selection of an appropriate level of control involves a determination of which (and how many) conflicts a driver should be able to perceive and avoid through the exercise of judgment. Where it is not reasonable to expect a driver to perceive and avoid a particular conflict, traffic controls must be imposed to assist.

<u>Two factors affect a driver's ability to avoid conflicts:</u>

1. A driver must be able to see a potentially conflicting vehicle or pedestrian in time to implement an avoidance maneuver, and
2. The volume levels that exist must present reasonable opportunities for a safe maneuver to take place.

The first involves considerations of sight distance and avoidance maneuvers, and the second involves an assessment of demand intensity, the complexity of potential conflicts that exist at a given intersection, and finally, the gaps available in major movements.

A rural intersection of two farm roads contains all of the potential conflicts illustrated in Figure 1. However, pedestrians are rare, and vehicular flows may be extremely low.

There is a low probability of any two vehicles and/or pedestrians attempting to use a common physical point simultaneously. At the junction between two major urban arterials the probability of vehicles or pedestrians on conflicting path-arriving simultaneously is quite high. The sections that follow discuss how a determination of an appropriate form intersection control can be made, highlighting the important factors to consider in making such critical decisions.

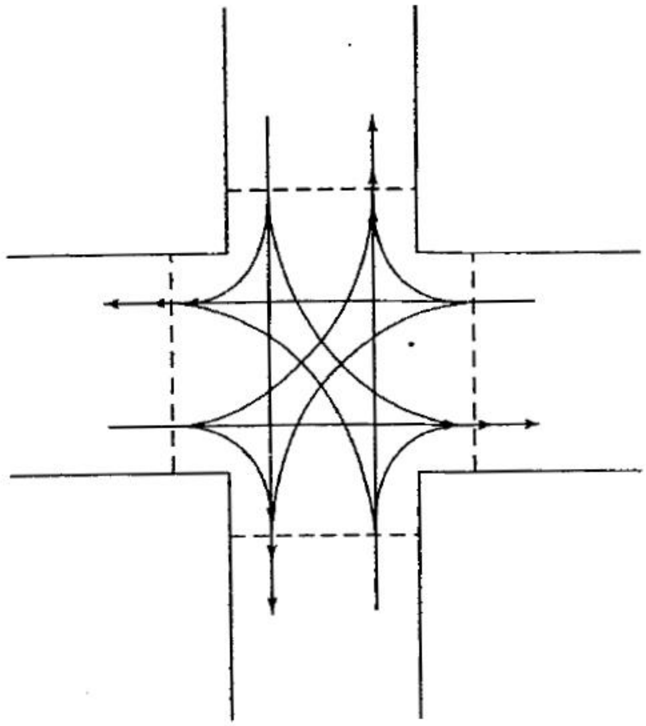


Figure 1: Typical Conflicts at a Four-Leg Intersection.

Level I Control: Basic Rules of the Road

Basic rules of the road apply at any intersection where right-of-way is not explicitly assigned through the use of traffic signals, STOP, or YIELD signs. These rules are spelled out in each state's vehicle and traffic law, and drivers are expected to know them. At intersections, all states follow a similar format. In the absence of control devices, the driver on the left must yield to the driver on the right when the vehicle on the right is approaching in a manner that may create an impending hazard.

In essence, the responsibility for avoiding a potential conflict is assigned to the vehicle on the left. Most state codes also specify that through vehicles have the right-of-way over turning vehicles at uncontrolled intersections.

Operating under basic rules of the road does not imply that no control devices are in place at or in advance of the interaction, although that could be the case. Use of street-name signs, other guide signs, or advance intersection warning signs do not change the application of the basic rules. They may, however, be able to contribute to the safety of the operation by calling the driver's attention to the existence and location of the intersection.

To safely operate under basic rules of the road, drivers on conflicting approaches must be able to see each other in time to assess whether an "impending hazard" is imposed and 'o take appropriate action to avoid an accident. Figure 2 illustrates a visibility triangle at a typical intersection. Sight distances must be analyzed to ensure that they are sufficient or drivers to judge and avoid conflicts.

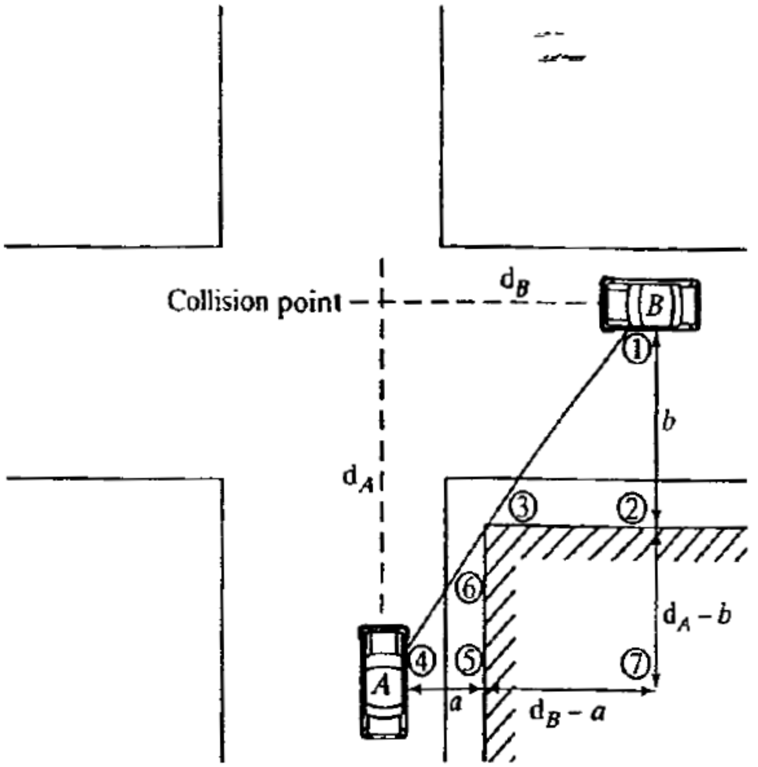


Figure 2: Visibility Triangle at an Intersection.

At intersections, sight distances are normally limited by buildings or other sight-line obstructions located on or near the comers. There are, of course, four sight triangles at every intersection with four approaches.

All must provide adequate visibility for basic rules of the road to be considered. At the point where the drivers of both approaching vehicles first see each other. Vehicle A is located a distance d_A of from the collision or conflict point, and Vehicle B is located a distance d_B from the collision point. The sight triangle must be sufficiently large to ensure that at no time could two vehicles be on conflicting paths at distances and speeds that might lead to an accident, without sufficient time and distance being available for either driver to take evasive action.

Note that the sight line forms three similar triangles with sides of the sight obstruction: A123, A147, and A645. From the similarity of the triangles, a relationship between the critical distances in Figure 2 can be established:

$$\frac{b}{d_B - a} = \frac{d_A - b}{a}$$

$$d_B = \frac{a\, d_A}{d_A - b} \qquad (1)$$

Where:
dA = distance from Vehicle A to the collision point, ft
dB = distance from Vehicle B to the collision point, ft
a = distance from driver position in Vehicle A to the sight obstruction, measured parallel to the path of Vehicle B, ft.
b = distance from driver position in Vehicle B to the sight obstruction, measured parallel to the path of Vehicle A, ft

Thus, when the position of one vehicle is known, the position of the other when they first become visible to each other can be computed. The triangle is dynamic, and the position of one vehicle affects the position of the other when visibility is achieved.

The American Association of State Highway and Transportation Officials (AASHTO) suggests that to ensure safe operation with no control, both drivers should be able to stop before reaching the collision point when they first see each other. In other words, both dA and dB should be equal to or greater than the safe stopping distance at the points where visibility is established. AASHTO standards [1] suggest that a driver reaction time of 2.5 seconds be used in estimating safe stopping distance and that the 85th percentile speed of immediately approaching vehicles be used. AASHTO does suggest, however, that drivers slow from their midblock speeds when approaching uncontrolled intersections, and it recommends use of an immediate approach speed that is assumed to be lower than the design speed of the facility. The safe stopping distance is given by:

$$d_s = 1.47\, S_i t + \frac{S_i^2}{30(0.348 \pm 0.01G)} \quad (2)$$

Where:
d_s = safe stopping distance, ft
Si = initial speed of vehicle, mi/hr
G = grade, %
t = reaction time, s
0.348 = standard friction factor for stopping maneuvers.

Using this equation, the following analysis steps may be used to test whether an intersection sight triangle meets these sight distance requirements:

1. Assume that Vehicle A is located one safe stopping distance from the collision point (i.e., dA = ds), using Equation 2. By convention. Vehicle A is generally selected as the vehicle on the minor street.
2. Using Equation 1, determine the location of Vehicle B when the drivers first see each other. This becomes the actual position of Vehicle B when visibility is established, d_{Bact}.
3. Because the avoidance rule requires that both vehicles have one safe stopping distance available, the minimum requirement for d_B is the safe stopping distance for Vehicle B, computed using Equation 2. This becomes d_{Bmin}.
4. For the intersection to be safely operated under basic rules of the road (i.e., with no control), $d_{Bact} \geq d_{Bmin}$.

Historically, another approach to ensuring safe operation with no control has also been used. In this case, to avoid collision from the point at which visibility is established Vehicle A must travel 18 feet past the collision point in the same time that Vehicle B travels to a point 12 feet before the collision point. This can be expressed as:

$$\frac{d_A + 18}{1.47\,S_A} = \frac{d_B - 12}{1.47\,S_B}$$

$$d_B = (d_A + 18)\frac{S_B}{S_A} + 12 \qquad (3)$$

Where all variables are as previously defined. This, in effect, provides another means of estimating the minimum required distance, dBmin. In conjunction with the four-step analysis process outlined previously, it can also be used as a criterion to ensure safe operation.

At any intersection, all of the sight triangles must be checked and must be safe to implement basic rules of the road. If, for any of the sight triangles, $d_{Bact} < d_{Bmin}$, then operation with no control cannot be permitted. When this is the case, there are three potential remedies:

- Implement intersection control, using STOP- of YIELD-control, or traffic signals.
- Lower the speed limit on the major street to a point where sight distances are adequate.
- Remove or reduce sight obstructions to provide adequate sight distances.

The first is the most common result. The exact form of control implemented would require consideration of warrants and other conditions, as discussed in subsequent portions of this chapter. The second approach is viable where sight distances at series of uncontrolled intersections can be remedied by a reduced but still reasonable speed limit. The latter depends on the type of obstruction and ownership rights.
Consider the intersection illustrated in Figure 3. It shows an intersection of a one-way minor street and a two way major street. In this case, two sight triangles must be analyzed. The 85th percentile immediate approach speeds are shown.

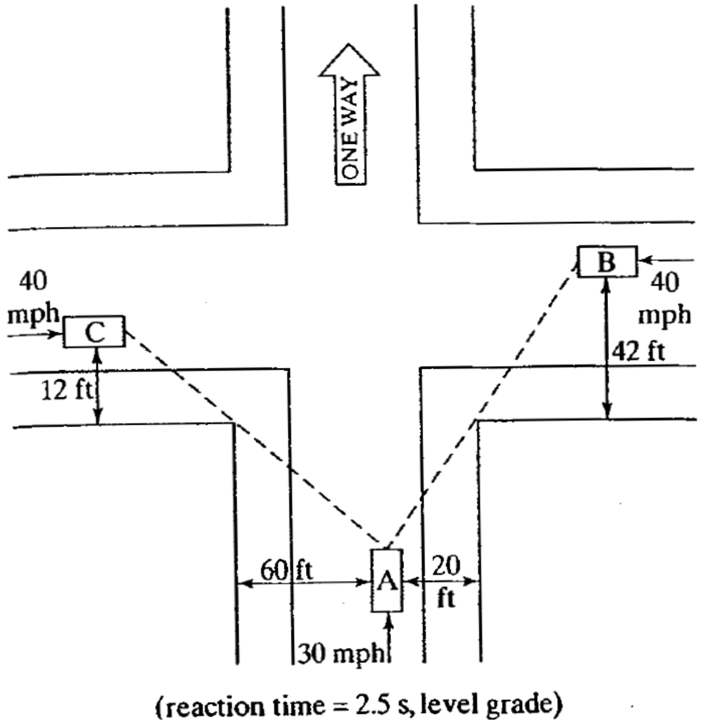


Figure 3: Sample Problem: Intersection Sight Distance.

First, it is assumed that Vehicle A is one safe stopping distance from the collision point:

$$d_A = 1.47 * 30 * 2.5 + \frac{30^2}{30(0.348 + 0)}$$
$$= 110.3 + 86.2 = 196.5 \text{ ft}$$

Where 2.5 s is the standard driver reaction time used in safe stopping sight distance computations. Using Equation 1, the actual position of Vehicle B when it is first visible to the driver of vehicle A is found:

$$d_{Bact} = \frac{a\, d_A}{d_A - b} = \frac{20 * 196.5}{196.5 - 42} = \frac{3{,}930}{154.5} = 25.4 \text{ ft}$$

This must be compared with the minimum requirement for dB, estimated as either one safe stopping distance (Equation 2), or using Equation 3:

$$d_{Bmin} = 1.47 * 40 * 2.5 + \frac{40^2}{30(0.348 + 0)}$$
$$= 147.0 + 153.3 = 300.3 \text{ ft}$$

or:

$$d_{Bmin} = (196.5 + 18)\frac{40}{30} + 12 = 298.0 \text{ ft}$$

In this case, both of the minimum requirements are similar, and both are far larger than the actual distance of 25.4 ft. Thus the sight triangle between Vehicles A and B fails to meet the criteria or safe operation under basic rules of the road.
Consider the actual meaning of this result. Clearly, if Vehicle A is 196.5 feet away from the collision point when Vehicle B is only 25.4 feet away from it, they will not collide.
Why, then, is this condition termed "unsafe?" It is unsafe because there could be a Vehicle B, further away than 25.4 feet, on a collision path with Vehicle A and the drivers would not be able to see each other.

Because the sight triangle between Vehicles A and B did not meet the sight-distance criteria, it is not necessary to check the sight triangle between vehicles A and C. Basic rules of the road may not be permitted at this intersection without reducing major street speeds or removing sight obstructions. This implies that, in many cases, YIELD or STOP control should be imposed on the minor street as a minimum form of control.
Even if the intersection met the sight-distance criteria, this does not mean that basic rules of the road should be applied to the intersection. Adequate sight distance is a necessary, but not sufficient, condition for adopting a "no-control" option. Traffic volumes or other conditions may make a higher level of control desirable or necessary.

Level II Control: YIELD and STOP Control

If a check of the intersection sight triangle indicates it would not be safe to apply the basic rules of the road, then as a minimum, some form of level II control is often imposed. Even if sight distances are safe for operating under no control, there may be other reasons to implement a higher level of control as well.
Usually, these would involve the intensity of traffic demand and the general complexity of the intersection environment.
The Manual of Uniform Traffic Control Devices '(MUTCD) gives some guidance as to conditions for which imposition of STOP or YIELD control is justified. It is not very specific, and it requires the exercise of engineering judgment.
The warrants shown are taken from the draft of the 2010 MUTCD, which has been available for review on line since December 2007.At this writing, final approval to the contents of this edition has not been obtained. Final approval and official publication is expected in late 2009 or early 2010.
The MUTCD gives some very general "guidance" for the imposition of either STOP signs or YIELD signs. These shown in Table1.

Table 1. Warrants for using 2-Way STOP or YIELD Control at an Intersection.

STOP or YIELD signs should be used at an intersection if one or more of the following conditions exist:

A. An intersection of a less important road with a main road where application of the normal right-of-way rule would not be expected to provide reasonable compliance with the law;

B. A street entering a designated through highway; and/or

C. An unsignalized intersection within a signalized area.

(*Source: Manual on Uniform Traffic Control Devices,* Draft, Federal Highway Administration, Washington DC, December 2007, p. 70, available at www.fhwa.com.)

These are very general. The first condition simply addresses a situation in which the sight triangle is insufficient to provide for safety. STOP or YIELD signs can be used to help establish a major or through road. If all unsignalized approaches to a major road are controlled by STOP or YIELD signs, through drivers have a clear right-of-way. The last condition addresses a situation in which virtually all intersections in an area or along an arterial are signalized. If a few isolated locations do not need to be signalized, then they should at least have STOP or YIELD signs.

Two-Way Stop Control

The most common form of level II control is the two-way STOP sign. In fact, such control may involve one or two STOP signs, depending on the number of intersection approaches. It is not all-way STOP control, which is discussed later in this lecture.
Under the heading of “guidance," the MUTCD suggests several conditions under which the use of STOP signs would be justified. Table 2 shows these warrants.
Warrant A establishes a reasonable level of major street traffic that would require use of a STOP sign to allow minor-street divers to select an appropriate gap in a busy traffic stream. Warrant B merely restates the need for STOP (or YIELD) control where a sight triangle at the intersection is found to be inadequate. Warrant C establishes criteria for using a STOP sign to correct a perceived accident problem.
The MUTCD is somewhat more explicit in dealing with inappropriate uses of the STOP sign. Under the heading of a “standard " (i.e., a mandatory condition), STOP (or YIELD) signs shall not be installed at intersections where traffic control signals are installed and operating, except where signal operation is a flashing red at all times, or where a channelized right turn exists. This disallows a past practice in which some jurisdictions turned signals off at night, leaving STOP signs in place for the evening hours. During the day, however, an unfamiliar diver approaching a green signal with a STOP sign could become significantly confused. The manual also disallows the use of portable or part-time STOP signs except for emergency and temporary traffic control.

Under the heading of "guidance," STOP signs should not be used for speed control, although this is frequently done on local streets designed in a straight grid pattern. In modern designs, street layout and geometric design would be used to discourage excessive speeds on local streets.

In general, STOP signs should be installed in a manner that minimizes the number of vehicles affected, which generally means installing them on the minor street.

AASHTO [7] also provides sight distance criteria STOP-controlled intersections. A methodology based on observed gap acceptance behavior of divers at STOP-control intersections is used. A standard stop location is assumed for the minor street vehicle (Vehicle A in Figure 2). The distance to the collision point (dA) has three components:

- Distance from the diver's eye to the front of the vehicle (assumed to be 8 feet).
- Distance from the front of the vehicle to the curb line (assumed to be 10 feet)
- Distance from the curb line to the center of the right most travel lane approaching from the left, or from the curb line to the left-most travel lane approaching from the right.

Table 2: Warrants for STOP Signs.

At intersections where a full stop is not necessary at all times, consideration should first be given to using less restrictive measures, such as YIELD signs.
The use of STOP signs on the minor street approaches should be considered if engineering judgment indicates that a stop is always required because of one or more of the following conditions:
A. The vehicular traffic volumes on the through street or highway exceed 6,000 veh/day; B. A restricted view exists that requires road users on the minor street approach to stop in order to adequately observe conflicting traffic on the through street or highway. C. Crash records indicate that 3 or more crashes that are susceptible to correction by installation of a STOP sign have been reported within a 12-month period, or that 5 or more such crashes have been reported within a 2-year period. Such crashes include right-angle collisions involving road users on the minor street approach failing to yield the right-of-way to traffic on the through street or highway.

(*Source: Manual of Uniform Traffic Control Devices*, Draft, Federal Highway Administration, Washington DC, December 2007, p. 71. available at www.fhwa.com.)

Thus:

$$d_{A\text{-}STOP} = 18 + d_{cl} \quad (4)$$

Where:

$d_{A\text{-}Stop}$ = distance of Vehicle A on a STOP-controlled approach from the collision point,

t_{cl} = distance from the curb line to the center of the closest travel lane from the direction under consideration, ft.

The required sight distances for Vehicle B, on the major street for STOP-controlled intersections is found as follows:

$$d_{Bmin} = 1.47 * S_{maj} * t_g \quad (5)$$

Where:
d_{Bmin} = minimum sight distance for Vehicle B approaching on major (uncontrolled) street, ft
S_{maj} = design speed of major street, mi/h
tg = average gap accepted by minor street diver to enter the major road, s

Average gaps accepted are best observed in the field for the situation under study. In general, they range from 6.5 seconds to 12.5 seconds depending on the minor street movement and vehicle type, as well as some of the specific geometric conditions that exist.
For most STOP-controlled intersections, the design vehicle is the passenger car, and the criteria for left-turns are used because they are the most restrictive. Trucks or combination vehicles are considered only when they make up a substantial proportion of the total traffic on the approach. Values for right-turn and through movements are used when no let-turn movement is present. For these typical conditions, AASHTO recommends the use of tg = 7.5 s.
Consider the case of a STOP-controlled approach at an intersection with a two-lane arterial with a design speed of 40 mi/h, as shown in Figure 4. Using Equation 4, the position of the stopped vehicle on the minor approach can be determined.

$$d_{A\text{-}STOP}(\text{from left}) = 18.0 + 6.0 = 24.0 \text{ ft}$$
$$d_{A\text{-}STOP}(\text{from right}) = 18.0 + 18.0 = 36.0 \text{ ft}$$

The minimum sight distance requirement for Vehicle B is determined from Equation 18-5, using a time gap (tg) of 7. 5 seconds for typical conditions.

$$d_{Bmin} = 1.47 * 40 * 7.5 = 441 \text{ ft}$$

Now the actual distance of Vehicle B from the collision point when visibility is established is determined using Equation 1:

$$d_{Bact}(\text{from left}) = \frac{36 * 24}{24 - 20} = 216 \text{ ft} < 441 \text{ ft}$$
$$d_{Bact}(\text{from right}) = \frac{16 * 34}{36 - 35} = 576 \text{ ft} > 441 \text{ ft}$$

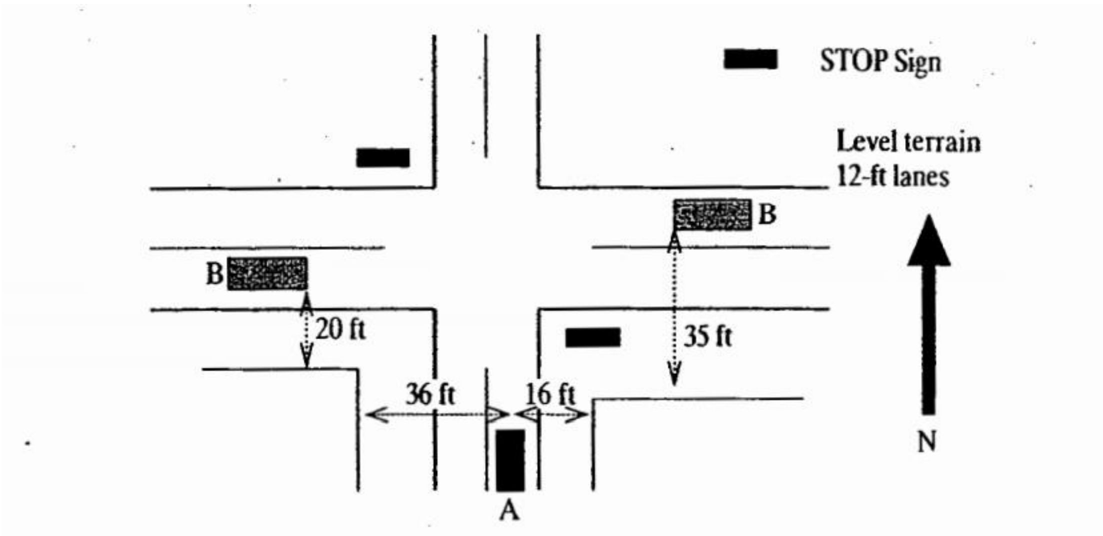


Figure 4: Sample Problem in STOP-Control Sight Distance Requirements.

In the case of a major street Vehicle B approaching from the left, there is not sufficient sight distance to meet the criteria. The sight distance for Vehicle B approaching from the right meets the criteria. Note that it is possible for d_{Bacl} to be negative. This would indicate there was no sight obstruction from the direction analyzed.
Where the STOP-sign sight-distance criterion is not met, it is recommended that speed limits be reduced (with signs posted) to a level that would allow appropriate sight distance to the minor street. Removal or cutting back of sight obstructions is also a potential solution, but this is often impossible in developed areas, where buildings are the principal obstructions.

Yield Control

A YIELD sign assigns right-of-way to the major uncontrolled street. It requires vehicles on the minor approaches to slow and yield the right-of-way to any major street vehicle approaching at a distance and speed that would present an impending hazard to the minor street vehicle if it entered the major street. Most state laws require that drivers on YIELD-controlled approaches slow to 8 to 10 mi/h before entering the major street.
Warrants for YIELD control in the MUTCD are hardly definitive, and they are given only under the heading of “options, “except for one relatively new mandatory usage. The warrants are summarized in Table 3.
The principal uses of the YIELD sign emanate from their mandatory use at roundabouts and Warrants B, C, and E. Warrant B is a common application where medians exist and are wide enough to store at least one crossing vehicle. In such cases, a vehicle crosses the first set of lanes, and may stop again in the median to seek another gap to cross the second set of lanes. Warrant C allows use of the YIELD sign to control channelized right turns at signalized and unsignalized intersections, and Warrant E allows their use at on-ramp or other merge situations. The latter is a frequent use in which adequate sight distance or geometry (i.e., inadequate length of the acceleration lane) make an uncontrolled merge potentially unsafe.

Table 3: Warrants for YIELD Signs.

A YIELD sign *shall* be used to assign right-of-way at the entrance to a roundabout. YIELD signs at roundabouts *shall* be used to control the approach roadways and *shall not* be used to control the circulatory roadway.
YIELD signs may be installed:
A. On approaches to a through street or highway where conditions are such that a stop is not always required.
B. At the second crossroad of a divided highway, where the median width at the intersection is 30 ft or greater. In this case, a STOP or YIELD sign may be installed at the entrance to the first roadway, and a YIELD sign may be installed at the entrance to the second roadway.
C. On a channelized turn lane that is separated from the adjacent travel lane by an island, even if the adjacent lanes at the intersection are controlled by a highway traffic control signal or by a STOP sign.
D. At an intersection where a special problem exists and where engineering judgment indicates the problem to be susceptible to correction by the use of YIELD signs.
E. Facing the entering roadway for a merge-type movement if engineering judgment indicates that the control is needed because acceleration geometry and/or sign distance is not sufficient for merging traffic operation.
(*Source: Manual of Uniform Traffic Control Devices*, Draft, Federal Highway Administration, Washington DC, p. 73, available at www.fhwa.com.)

There has been some controversy over the use of YIELD signs at normal crossings. Because YIELD signs require divers to slow down, the sight triangle may be analyzed using the legal reduced approach speed. In 2000, the Millennium Edition of the MUTCD required that sight distance sufficient for safety at the normal approach speed be present whenever a YIELD sign was used. This greatly discouraged their use at regular intersections. This prescription is expected to be removed in the forthcoming 2010 edition of the manual.

Multiway Stop Control

Multiway STOP control, where all intersection approaches are controlled using STOP signs, remains a controversial form of control. Some agencies find it attractive, primarily as a safety measure. Others believe the confusion that drivers often exhibit when confronted by this form of control negates any of the benefits it might provide.

MUTCD warrants and provisions with regard to Multiway STOP control reflect this ongoing controversy. Multiway STOP control is most often used where there are significant conflicts between vehicles and pedestrians and/or bicyclists in all directions, and where vehicular demands on the intersecting roadways are approximately equal. Table 4 shows the warrants for Multiway STOP control.

Note that such control is generally implemented as a safety measure because operations at such locations are often not very efficient the fourth edition of the Highway Capacity Manual, [3] includes a methodology for analysis of the capacity and level of service provided by Multiway STOP control.

Table 4: Warrants for Multiway STOP Signs.

The following criteria should be considered in the engineering study for a multiway STOP sign:

A. Where traffic control signals are justified, the multiway STOP is an interim measure that can be installed quickly to control traffic while arrangements are being made for the installation of the traffic control signal.

B. Five or more reported crashes in a 12-month period that are susceptible to correction by a multiway STOP installation. Such crashes include right- and left-turn collisions as well as right-angle collisions.

C. Minimum volumes:

1. The vehicular volume entering the intersection from the major street approaches (total of both approaches) averages at least 300 veh/h for any 8 hours of an average day, and
2. The combined vehicular, pedestrian, and bicycle volume entering the intersection from the minor street approaches (total of both approaches) averages at least 200 units/h for the same 8 hours, with an average delay to minor-street vehicular traffic of at least 30 s/veh during the highest hour, but
3. If the 85th percentile approach speed of the major highway exceeds 40 mi/h, the minimum vehicular volume warrants are 70% of the above values.

D. Where no single criterion is satisfied, but where criteria B., C1. and C2 are all satisfied to 80% of the minimum values. Criterion C3 is excluded from this condition.

(*Source: Manual on Uniform Traffic Control Devices*, Draft, Federal Highway Administration, Washington DC, December 2007, p. 72, available at www.fhwa.com.)

Level III Control: Traffic Control Signals

The ultimate form of intersection control is the traffic signal. Because it alternately assigns right-of-way to specific movements, it can substantially reduce the number and nature of intersection conflicts as no other form of control can.

If divers obey the signal, then diver judgment is not needed to avoid some of the most critical intersection conflicts. Imposition of traffic signal control does not, however, remove all conflicts rom the realm of driver judgment. At two-phase signals, where all left-turns are made against an opposing vehicular flow, drivers must still evaluate and select gaps in opposing traffic through which to safely turn. At virtually all signals, some pedestrian-vehicle and bicycle -vehicle conflicts remain between legal movements, and driver vigilance and judgment are still required to avoid accidents. Nevertheless, divers at signalized intersections do not have to negotiate the critical conflicts between crossing vehicle streams, and where exclusive left-turn phases are provided, critical conflicts between left turns and opposing through vehicles are also eliminated through signal control. This chapter deals with the issue of whether or not signal control is warranted or needed. Given that it is needed. Next lecture deals with the design of a specific phasing plan and the timing of the signal.

Although warrants and other criteria for STOP and YIELD signs are somewhat general in the MUTCD, warrants for signals are quite detailed. The cost involved in installation of traffic signals (e.g., power supply, signal controller, detectors, signal heads, and support structures, and other items) is considerably higher than for STOP or YIELD signs and can run into the hundreds of thousands of dollars for complex intersections. Because of this, and because traffic signals introduce a fixed source of delay into the system, it is important that they not be overused; they should be installed only where no other solution or form of control would be effective in assuring safety and efficiency at the intersection.

Advantages of Traffic Signal Control

The Millennium Edition of the MUTCD lists the following advantages of traffic control signals that are " properly designed, located, operated, and maintained" [MUTCD, Millennium Edition, p. 4b-2]. These advantages include:

1) They provide for the orderly movement of traffic.
2) They increase the traffic-handling capacity of the intersection if proper physical layouts and control measures are used and if the signal timing is reviewed and updated on a regular basis (every two years) to ensure that it satisfies the current traffic demands.
3) They reduce the frequency and severity of certain types of crashes, especially right-angle collisions.
4) They are coordinated to provide for continuous or nearly continuous movement at a definite speed along a given route under favorable conditions.
5) They are used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross

These specific advantages address the primary reasons why a traffic signal would be installed: to increase capacity (thereby improving level of service), to improve safety, and to provide for orderly movement through a complex situation. Coordination of signals provides other benefits, but not all signals are necessarily coordinated.

Disadvantages of Traffic Signal Control

The description of the second advantage in the earlier list indicates that capacity is increased by a well-designed signal at a well-designed intersection. Poor design of either the signalization or the geometry of the intersection can significantly reduce the benefits achieved or negate them entirely. Improperly designed traffic signals, or the placement of a signal where it is not justified, can lead to some of the following ~, disadvantages [MUTCD, Millennium Edition, p. 4B-3]:

1) Excessive delay
2) Excessive disobedience of the signal indications
3) Increased use of less adequate routes as road users attempt to avoid the traffic control signal
4) Significant increases in the frequency of collisions (especially ear-end collisions)

Item 4 is of some interest. Even when they are properly installed and well designed, traffic signal controls can lead to increases in rear-end accidents because of the cyclical stopping of traffic.
Where safety is concerned, signals can reduce the number of right-angle, turning, and pedestrian/bicycle accidents; they might cause an increase in rear-end collisions (which tend to be less severe); they will have almost no impact on head-on or sideswipe accidents, or on single-vehicle accidents involving fixed objects.
Excessive delay can result from an improperly installed signal, but it can also occur if the signal timing is inappropriate. In general, excessive delay results from cycle lengths that are either too long or too short for the existing demands at the intersection. Further, divers tend to assume that a signal is broken if they experience an excessive wait, particularly when there is little or no demand occurring on the cross street.

Warrants for Traffic Signals

The forthcoming 2009/2010 MUTCD specifies nine different warrants that justify the installation of a traffic signal. The ninth is just being added in this edition. It covers the installation of a signal in coordination with a railroad crossing. Satisfying one or more of the warrants for signalization does m\ require or justify the installation of a signal. The manual requires, however, that a comprehensive engineering study be conducted to determine whether or not installation of a signal is justified. The study must include applicable factors reflected in the specified warrants but could extend to other factors as well. However, traffic signal control should not be implemented if none of the warrants are met. The warrants, therefore, still require the exercise of engineering judgment. In the final analysis, if engineering studies and/or judgment indicate that signal installation will not improve the overall safety or operational efficiency at a candidate location, it should not be installed.
Although offered only under the heading of an option. The MUTCD suggests that the following data be included in an engineering study of the need for a traffic signal [2009/2010 MUTCD, Draft, p. 268]:

1. The number of vehicles entering the intersection 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.

2. Vehicular volumes for each traffic movement, from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, public-transit vehicles, and in some locations, bicycles), 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.

3. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in Item 3 above and during 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.

4. Information about nearby facilities and activity centers that serve the young, elderly, and/or persons with disabilities, including requests from persons will1 disabilities for accessible parking improvements31 the location under study. These persons might not 1 adequately reflected in the pedestrian volume count if the absence of a signal restrains their mobility.

5. The posted or statutory speed limit or the 85th percentile speed on the uncontrolled approaches to the location.

6. A condition diagram showing details of the physical layout, including such features as intersection geometries, 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.

7. A collision diagram showing crash experience by type, location, direction of movement, severity, weather, time of day, date, and day of week for at least one year.

MUTCD also recommends collection of stopped-time delay data and queuing information at some locations where these are thought to be problems. This data will allow the engineer to fully evaluate whether or not " the intersection satisfies the requirements of one or more of the following warrants:
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 6: Crash Experience.
Warrant 8: Roadway Network.
Warrant 9: Intersection near a Highway-Rail Crossing.

It also provides a sufficient base for the exercise of engineering judgment in determining whether a traffic signal should be installed at the study location. Each of these warrants is presented and discussed in the sections that follow. In most cases, an engineering study includes data from an existing location. In some cases, however, consideration of signalization relates to a future situation or design. In such cases, forecast demand volumes may be used to compare with the criteria in the warrants.

Warrant 1: Eight-Hour Vehicular Volume

The eight-hour vehicular volume warrant represents a merging of three different warrants in the pre-2000 MUTCD (old Warrants 1, 2, and 8). It addresses the need for signalization for conditions that exist over extended periods of the day (a minimum of eight hours). Two of the most fundamental reasons for signalization are addressed:

- Heavy volumes on conflicting crossmovements that make it impractical for drivers to select gaps in an uninterrupted traffic stream through which to safely pass. This requirement is often referred to as the "minimum vehicular volume" condition (Condition A).
- Vehicular volumes on the major street are so heavy that no minor-street vehicle can safely pass through the major-street traffic stream without the aid of signals. This requirement is often referred to as the "interruption of continuous traffic" condition (Condition B)

Details of this warrant are shown in Table 18.5. The warrant is met when:

- Either Condition A or Condition B is met to the 100% level.
- Either Condition A or Condition B is met to the 70% level, where the intersection is located in an isolated community of population 10, 000 or less, or where the major-street approach speed is 40 mi/h or higher.
- Both Conditions A and B are met to the 80% level.

Note that in applying these warrants, the major-street volume criteria are elated to the total volume in both directions, whereas the minor-street volume criteria are applied to the highest volume in one direction. The volume criteria in Table 5 must be met for a minimum of eight hours on a typical day. The eight hours do not have to be consecutive, and they often involve four hours around the mooning peak and four hours around the evening peak. Major- and minor-street volumes must be for the same eight hours, however.
Either of the intersecting streets may be treated as the “major” approach, but the designation must be consistent for a given application. If the designation of the “major” street is not obvious, a warrant analysis can be conducted considering each as the “major " street in turn. Although the designation of the major street may not be changed within any one analysis, the direction of peak one-way volume for the minor street need not be consistent.

The 70% reduction allowed for rural communities of population 10,000 or less reflects the fact that drivers in small communities have little experience in driving under congested situations. They will require the guidance of traffic signal control at volume levels lower than those for drivers more used to driving in congested situations. The same reduction applies where the major-street speed limit is 40 mi/h or greater. Because gap selection is more difficult through a higher-speed major-street flow, signals are justified at lower volumes.

The various elements of the eight-hour vehicular volume warrant are historically the oldest of the warrants, having been initially formulated and disseminated in the 1930s.

Table 5: Warrant 1: Eight-Hour Vehicular Volume.

Condition A: Minimum Vehicular Volume								
Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total, both approaches)			Vehicles per hour on higher-volume minor street approach (one direction only)			
Major Street	Minor Street	100%	80%	70%	100%	80%	70%
1	1	500	400	350	150	120	105
2 or more	1	600	480	420	150	120	105
2 or more	2 or more	600	480	420	200	160	140
1	2 or more	500	400	350	200	160	140

Condition B: Interruption of Continuous Traffic							
Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total, both approaches)			Vehicles per hour on higher-volume minor street approach (one direction only)		
Major Street	Minor Street	100%	80%	70%	100%	80%	70%
1	1	750	600	525	75	60	53
2 or more	1	900	720	630	75	60	53
2 or more	2 or more	900	720	630	100	80	70
1	2 or more	750	600	525	100	80	70

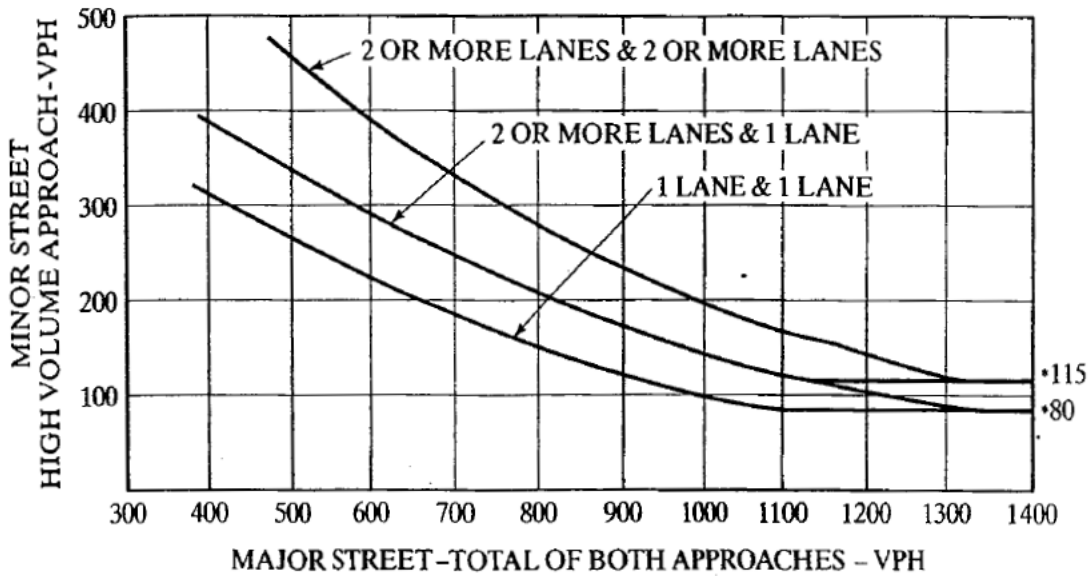
(*Source:* Used with permission of Federal Highway Administration, US Department of Transportation, *Manual on Uniform Traffic Control Devices,* Millennium Edition, Table 4C-1, p. 4C-5, Washington DC, 2000.)

Warrant 2: Four-Hour Vehicular Volume

The four-hour vehicular volume warrant was introduced in the 1970s to assist in the evaluation of situations where volume levels requiring signal control might exist for periods shorter than eight hours. Prior to the MUTCD Millennium Edition, this was old Warrant 9. Figure 5 shows the warrant, which is in the form of a continuous graph. Because this warrant is expressed as a continuous relationship between major and minor street volumes, it addresses a wide variety of conditions. Indeed, Conditions A and B of the eight-hour warrant represent two points in such a continuum for each configuration, but the older eight-hour warrant did not investigate or create criteria for the full range of potential conditions.
Figure 5 (a) is the warrant for normal conditions, and Figure 5 (b) elects the 70% reduction applied to isolated small communities (with population less than 10,000) or where the major-street speed limit is above 40 mi/h. Because the four-hour warrant represents a continuous set of conditions. There is no need to include an 80% reduction for two discrete conditions within the relationship.

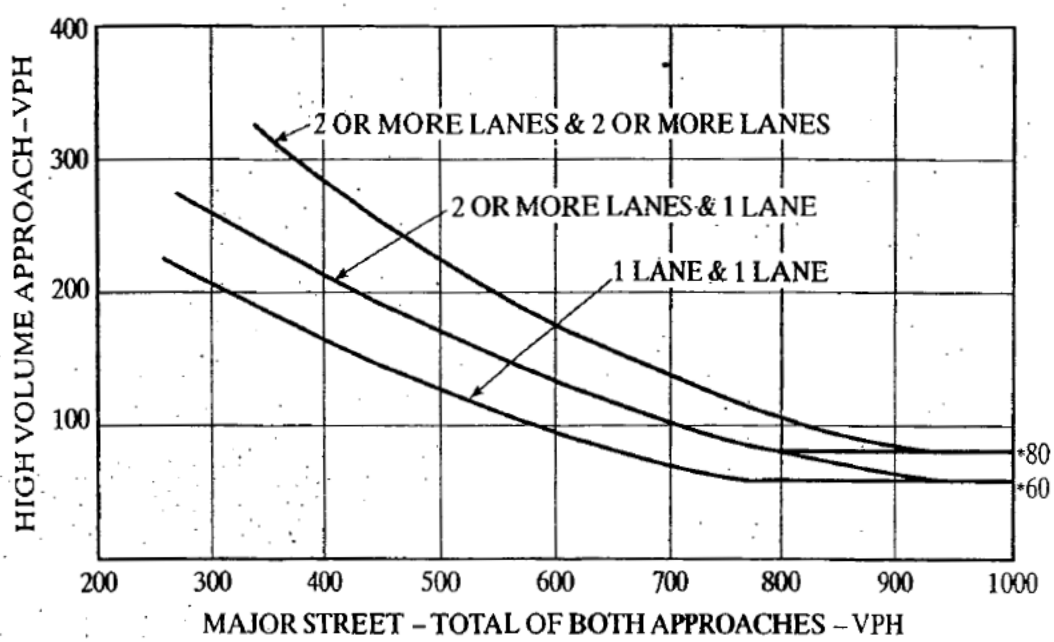
1. To test the warrant, the two-way major-street volume is plotted against the highest one-way volume on the minor street for each hour of the study period. To meet the warrant, at least four hours must plot above the appropriate decision curve. The three curves represent intersections of (1) two streets with one lane in each direction,
2. One street with one lane in each direction with another having two or more lanes in each direction, and

3. Two streets with more than one lane in each direction. In Case (2), the distinction between which intersecting street has one lane in each direction (major or minor) is no longer relevant, except for the footnotes.



*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.

(a) Normal Conditions



*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.

(b) Criteria for Small Communities (pop< 1O, OOO) or High Major Street Approach Speed (≥40 mi/h).

Figure 5: Warrant 2: Four-Hour Vehicular Volume

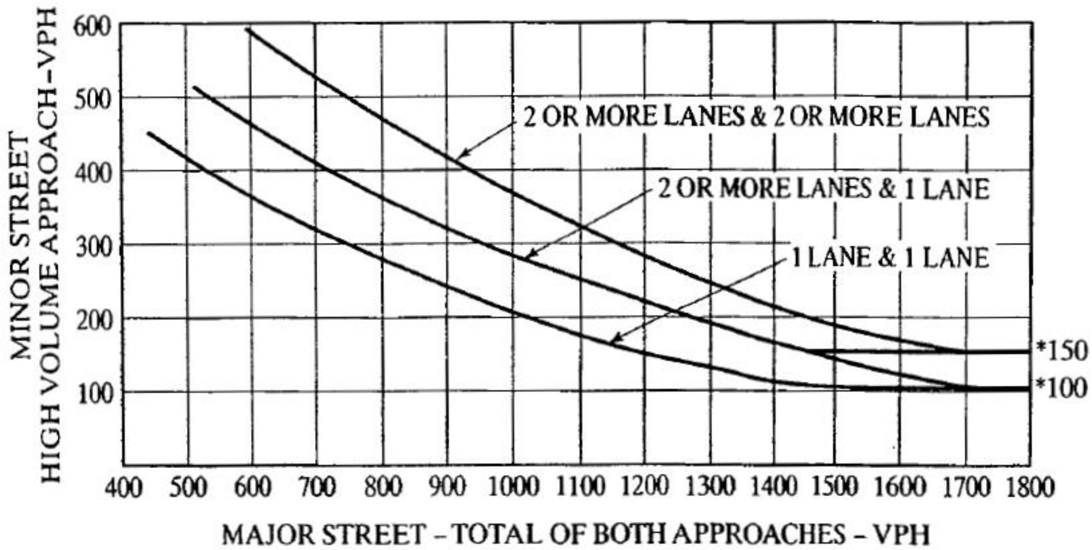
(Source: Used with permission of Federal Highway Administration, U.S. Department of Transportation, Manual on Uniform Traffic Control Devices, Millennium Edition, Figures 4C-1,4C-2, p. 4C-7, Washington DC, 2000.)

Warrant 3: Peak Hour

Warrant 3 addresses two critical situations that might exist for only one hour of a typical day. The first is a volume condition similar in form to Warrant 2, and shown in Figure 6 (old Warrant 11). The second is a delay warrant (old Warrant 10). If either condition is satisfied, the peak-hour warrant is met.

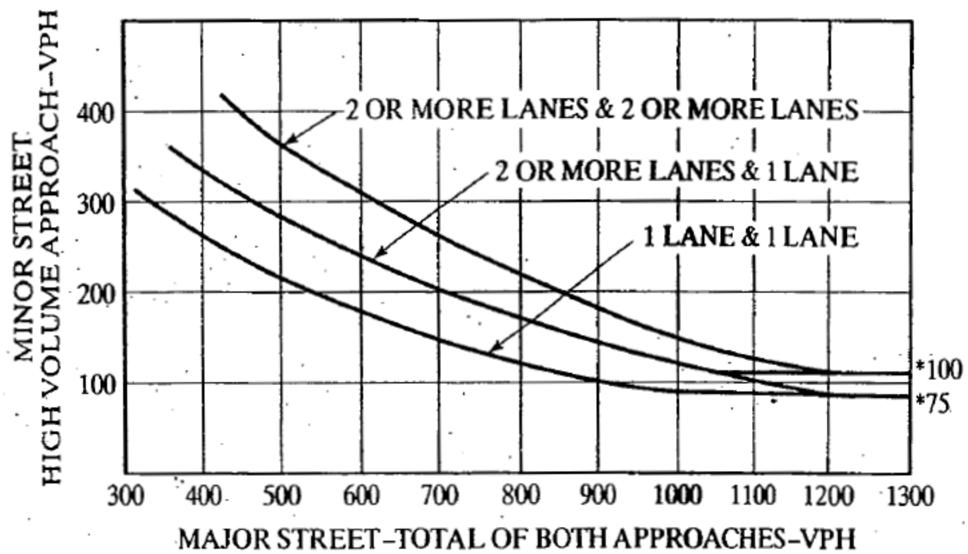
The volume portion of the warrant is implemented in the same manner as the four-hour warrant. For each hour of the study, the two-way major street volume is plotted against the high single-direction volume on the minor Meet. For the Peak-Hour Volume Warrant, however, only we hour must plot above the appropriate decision line to meet the criteria. Criteria are given for normal conditions in Figure 6 (a), and the 70% criteria for small isolated Figure 18.6 (b). The Peak-Hour Delay Warrant is summarized in Table 6. It is important to recognize that the delay portion of Warrant 3 applies only to cases in which STOP control is already in effect for the minor street. Thus delay during the peak hour is not a criterion that allows going from no control immunities and high major-street speeds are shown in or YIELD control to signalization directly.

The MUTCD also emphasizes that the Peak-Hour War- rant should be applied only in special 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.



*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.

(a) Normal Conditions



*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.

(b) Criteria for Small Communities (Pop <10,000) or High Major Street Approach Speed (≥40 mi/h)

Figure 6: Warrant 3A: Peak Hour Volume.

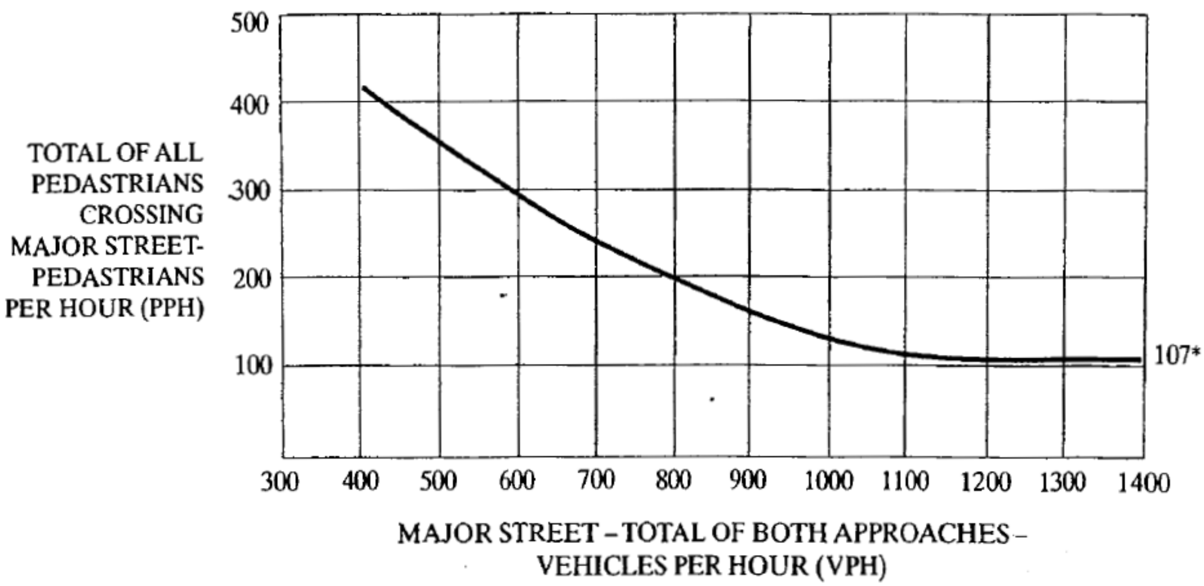
{Source: Used with permission of Federal Highway Administration, U.S. Department of transportation, Manual on Uniform Traffic Control Devices, Millennium Edition, Figures 4C-3,4C-4, p. 4C-9, Washington DC, 2000.).

Warrant 4: Pedestrians

The Pedestrian Warrant addresses situations in which the need for signalization is the frequency of vehicle-pedestrian conflicts and the inability of pedestrians to avoid such conflicts due to the volume of traffic present. Signals may be placed under this warrant at midblock locations, as well as at intersections.

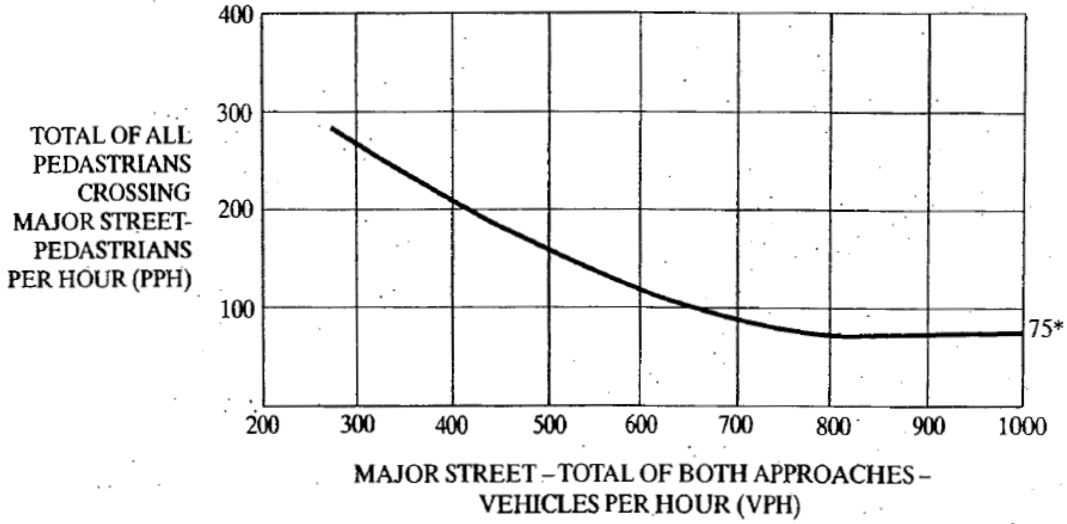
This warrant is met when any four hourly plots of total pedestrians crossing the major street and the total major street vehicular traffic falls over the line in Figure 7 (a).or when any one similar hourly plot falls above the line in Figure 8 (a). If the location is in a built-up area of a community (population less than 10,000) or where the posted or statutory speed limit, or the 85th percentile approach speed exceeds 35 mi/h. Figures 7 (b) and 8 (b) may be used.

The figures address cases in which a steadier pedestrian flow over four hours requires signal control and "the case in which a single peak hour has pedestrian-vehicle conflicts that must be signal controlled. The (b) figures apply the same 70%reduction in criteria that is used in conjunction with vehicular volume criteria in Warrants 1, 2, and 3.



*Note: 107 pph applies as the lower threshold volume.

(a) Normal Criteria.

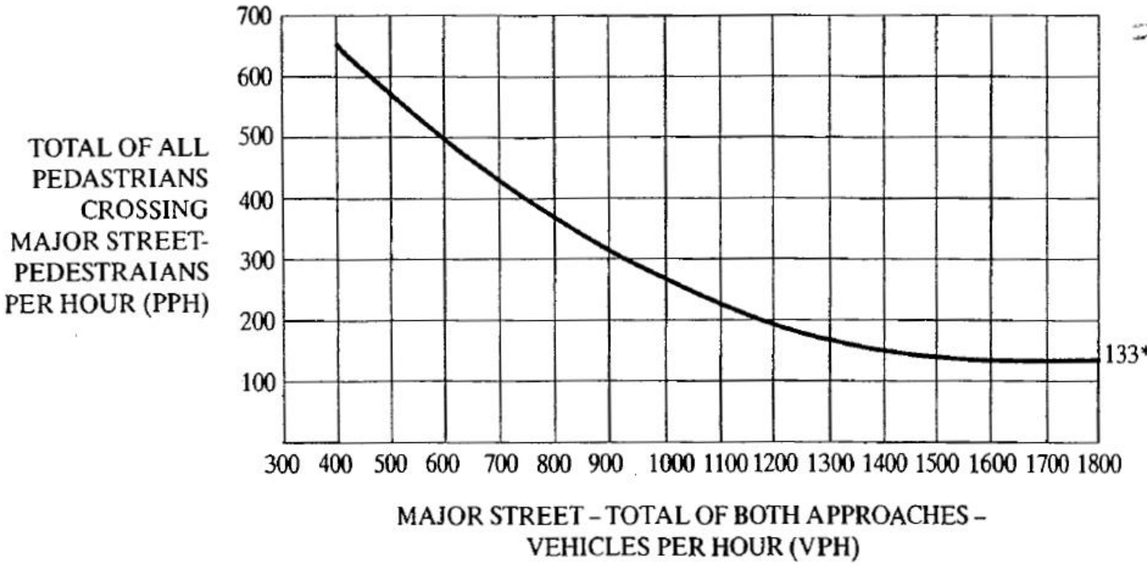


*Note: 75 pph applies as the lower threshold volume.

(b) Criteria for Small Communities (Pop <10,000) or High Major Street Approach Speed (> 35 mi/h)

Figure 7: Four-Hour Pedestrian Warrant.

(Source: Manual of Uniform Traffic Control Devices, Draft, Federal Highway Administration, Washington DC, December 2007, Figures 4C-5and4C-7.).



*Note: 133 pph applies as the lower threshold volume.

(a) Normal Criteria.

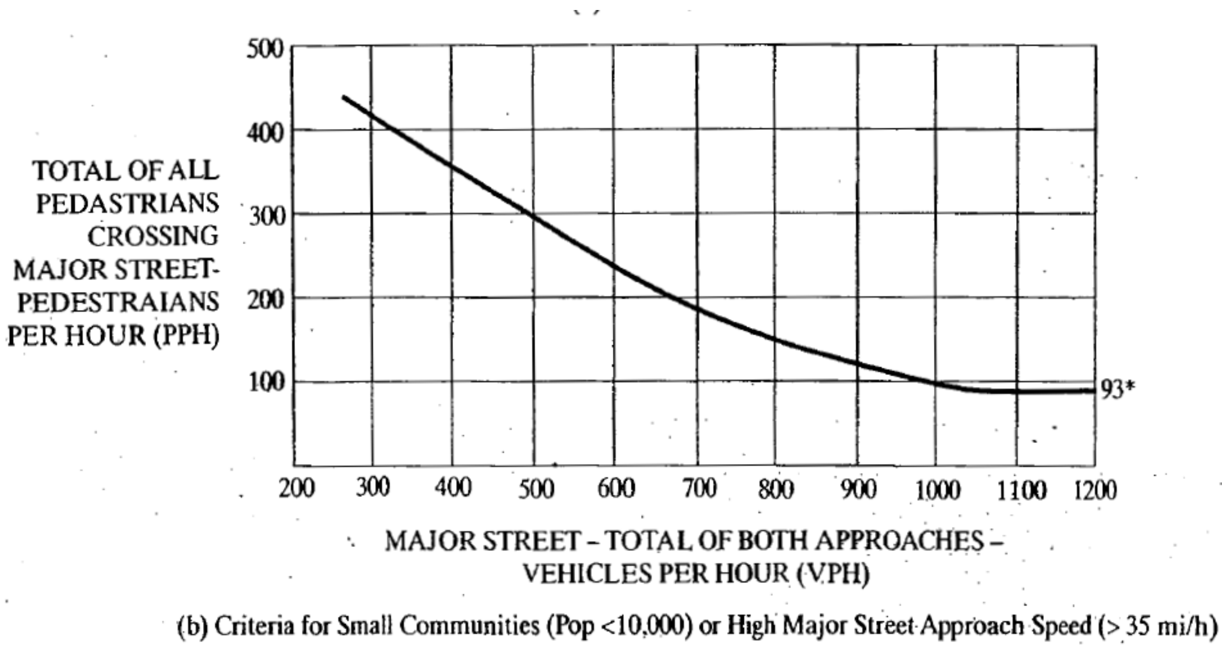


Figure 8 Peak-Hour Pedestrian Warrant.

{Source: Manual of Uniform Traffic Control Devices, Draft, Federal Highway Administration, Washington DC, Draft 2007, Figures 4C-6and 4C-8.).

If the traffic signal is justified at an intersection by this warrant only, it will usually be at least a semi-actuated signal (a full actuated signal is also a possibility at an isolated intersection) with pedestrian pushbuttons and signal heads for pedestrians crossing the major street. If it is within a coordinated signal system, it would also be coordinated into the system. If such a signal is located in midblock, it will always be pedestrian actuated, and parking and other sight restrictions should be eliminated within 20 feet of both sides of the crosswalk. Standard reinforcing markings and signs should also be provided.

If the intersection meets this warrant but also meets other vehicular warrants, any type of signal could be installed as appropriate to other conditions. Pedestrian signal heads would be required for major-street crossings. Pedestrian pushbuttons would be installed unless the vehicular signal timing safely accommodates pedestrians in every signal cycle.

A signal would not normally be implemented under this warrant if there is another signal within 300 feet of the location. Placement of a signal so close to another would only be permitted if did not disrupt progressive flow on the major street.

Pedestrian volume criteria may be reduced by as much as 50% if the 15th-percentile crossing speed is less than 3.5 mi/h, as might be the case where elderly, very young, or disabled pedestrians are present in significant percentages.

Warrant 5: School Crossing

This warrant is similar to the pedestrian warrant but is limited to application at designated school crossing locations, either at intersections or at midblock locations. The warrant requires the study of available gaps to see whether they are "acceptable “for children to cross through. An acceptable gap would include the crossing time, buffer time, and an allowance for groups of children to start crossing the street. The frequency of acceptable gaps should be no less than one for each minute during which school children are crossing. The minimum number of children crossing the major street is 20 during the highest crossing hour.
Traffic signals are rarely implemented under this warrant. Children do not usually, observe and obey signals regularly, particularly if they are very young. Thus traffic signals would have to be augmented by crossing guards in most cases. Except in unusual circumstances involving a very heavily traveled major street, the crossing guard, perhaps augmented with STOP signs, would suffice under most circumstances without signalization. Where extremely high volumes of school children cross a very wide and heavily traveled major street, overpasses or underpasses should be provided with barriers preventing entry onto the street.

Warrant 6: Coordinated Signal System

Signal coordination and progression systems for arterials and networks will discussed later. Critical to such systems is the maintenance of platoons of vehicles moving together through a "green wave" as they progress along an arterial. If the distance between two adjacent coordinated signals is too large, platoons begin to dissipate and the positive impact of the progression is sharply reduced. In such cases, the traffic engineer may place a signal at an intermediate intersection where it would not otherwise be warranted to reinforce the coordination scheme and to help maintain platoon coherence. The application of this warrant, shown in Table 7, should not result in signal spacing of less than 1,000 feet. Such signals, when placed, are often referred to as "spacer signals." The two criteria are similar but not exactly the same. Inserting a signal in a one-way progression is always possible without damaging the progression. On a two-way street, it is not always possible to place a signal that will maintain the progression in both directions acceptably. This issue is discussed in greater detail in next lecture.

Warrant 7: Crash Experience

The Crash Experience Warrant addresses cases in which a traffic control signal would be installed to alleviate an observed high-accident occurrence at the intersection. The criteria are summarized in Table 8.
The requirement for an adequate trial of altema1methods means that either YIELD or STOP control is already in place and properly enforced. These types of control can also address many of the same accident problems as signalization. Thus a signal is justified only when these lesser measures have failed to address the situation adequately.
Accidents that are susceptible to correction by signalization include right-angle accidents, accidents involving turning vehicles from the two streets, and accidents between vehicles and

pedestrians crossing the street on which the vehicle is traveling. Rear-end accidents are often increased with imposition of traffic signals (or STOP/YIELD signs) because some drivers may be induced to stop quickly or suddenly. Head-on and sideswipe collisions are not addressed by signalization; accidents between vehicles and fixed objects at comers are also not correctable through signalization.

Table 7: Warrant 6: Coordinated Signal System

The need for a traffic control signal shall be considered if an engineering study finds that one of the following criteria is met:
1. 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. 2. 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.

(*Source:* Used by permission of Federal Highway Administration, US Dept. of Transportation, *Manual on Uniform Traffic Control Devices,* Millennium Edition, Washington DC, 2001, p. 4C-12.)

Table 8: Warrant 7: Crash Experience

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

1. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency, and
2. Five or more reported crashes of types susceptible to correction by a traffic control signal have occurred within a 12-month period, each involving an personal injury or property damage apparently exceeding the applicable requirements for a reportable crash, and
3. For each of any 8 hours of the day, vehicles per hour (vph) given in both of the 80% columns of Condition A (in Warrant 1) or the vph in both of the 80% columns of Condition B (in Warrant 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% of the requirements specified in the Pedestrian Volume warrant. These 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 the 8 hours.

Warrant 8: Road network

This warrant addresses a developing situation (i.e., a case in which present volumes would not justify signalization but where new development is expected to generate substantial traffic that would justify signalization). The MUTCD also allows other warrants to be applied based on properly forecast vehicular and pedestrian volumes.
Large traffic generators, such as regional shopping centers, sports stadiums and arenas, and similar facilities, are often built in areas that are sparsely populated and where existing roadways have light traffic. Such projects often require substantial roadway improvements that change the physical layout of the roadway network and create new or substantially enlarged intersections that will require signalization. Generally, the "existing" situation is irrelevant to the situation being assessed. The warrant is described in Table 9.
"Immediately projected" generally refers to the traffic expected on day one of the opening of new facilities and/or traffic generators that create the need for signalization.

Table 9: Warrant 8: Roadway Network.

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:

1. The intersection has a total existing, or immediately projected, entering volume of at least 1,000 veh/h during the peak hour of a typical weekday, and has 5-year projected traffic volumes, based upon an engineering study, that meet one or more of Warrants 1, 2 and 3 during an average weekday, or
2. The intersection has a total existing of immediately projected entering volume of at least 1,000 veh/h for each of any 5 hours of a non-normal business day (Saturday or Sunday).

A major route as used in this warrant shall have one or more of the following characteristics:

1. It is part of the street or highway system that serves as the principal roadway network for through traffic flow, or
2. It includes rural or suburban highways outside, entering, or traversing a city, or
3. It appears as a major route on an official plan, such as a major street plan in an urban area traffic and transportation study.

(*Source:* Used by permission of Federal Highway Administration, US Dept. of Transportation, *Manual on Uniform Traffic Control Devices*. Millennium Edition, Washington DC, 2000, pp. 4C-13, 4C-14.)

Warrant 9: Intersection near a Highway-Rail Grade Crossing

This-is a new warrant being added to the forthcoming 2010 MUTCD. It addresses a unique situation: an intersection that does not meet any other warrant for signalization but that is close enough to a highway-railroad crossing to s present a hazard. Table 10 shows the detailed criteria for the warrant.

Figure 9 applies when there is only one lane I approaching the intersection at the track- crossing location, and Figure 10 applied where there are two or more lanes approaching the track-crossing location.

The minor-street volume used in entering either Figure 9 or 10 may be multiplied by up to three adjustment factors:

(1) An adjustment for train volume (Table 11),

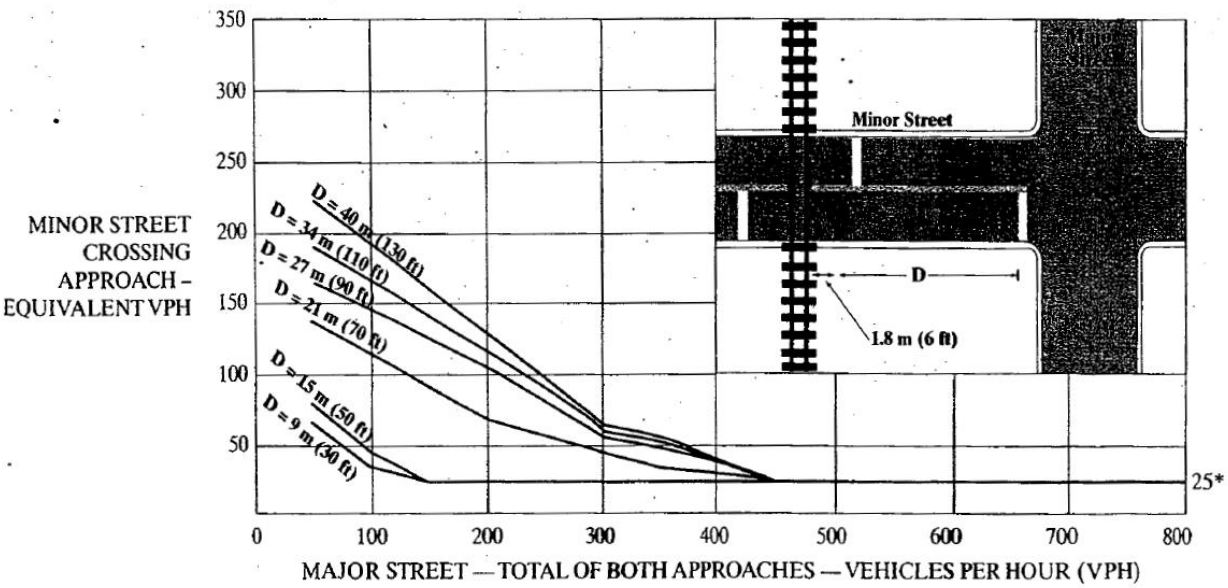
(2) An adjustment for presence of high-occupancy buses (Table 12), and

(3) An adjustment for truck presence (Table 18.13). The base conditions for Figures 9 and 10 include four trains per day, no buses, and 10% trucks.

Table 10: Warrant 9: Intersection Near a Highway-Rail Grade Crossing

The need for a traffic control signal shall be considered if an engineering study finds that both of the following criteria are met:
1. A highway-rail grade crossing exists on a approach controlled by a STOP or YIELD sign and the center of the track nearest to the intersection is within 140 ft of the stop line on the approach, and 2. During the highest traffic volume hour during which trains use the crossing, the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding vehicles per hour on the minor-street approach that crosses the track (one direction only) falls above the applicable curve in Figure 18.9 or 18.10 for the existing combination of approach lanes over the track and distance D, which is the clear storage distance (between the grade crossing stop line and the near curb line of the major street).

(*Source: Manual of Uniform Traffic Control Devices,* Draft, Federal Highway Administration, Washington DC, December 2007, pp. 273–274.)



*Note: 25 vph applies as the lower threshold volume.

Figure 9: Warrant 9: Railroad Crossings for One-Lane Approaches
(Source: Manual of Uniform Traffic Control Dev/m, Draft, Federal Highway Administration, Washington DC, December 2007, Figure 4C-9.)

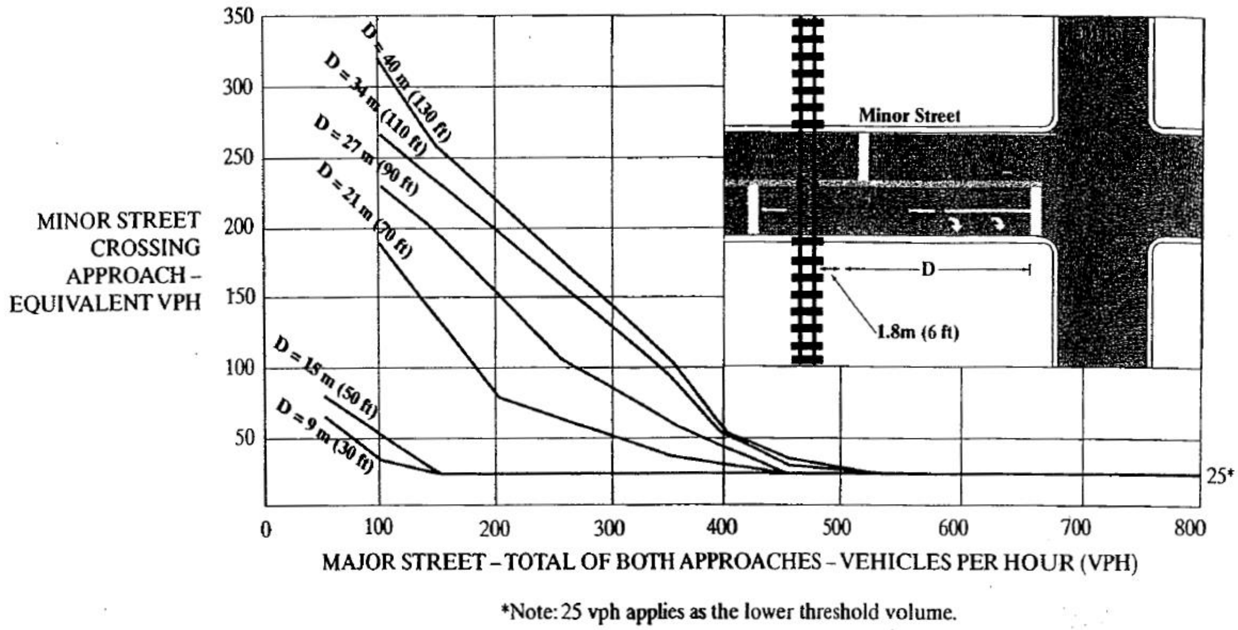


Figure 10: Warrant 9: Railroad Crossings for Two or More-Lane Approaches
(Source: Manual of Uniform Traffic Control Devices, Draft, Federal Highway Administration, Washington DC, December 2007, Figure 4C-9.).

Table 11: Adjustment Factor for Train Frequency.

Trains per Day	Adjustment Factor
1	0.67
2	0.91
3–5	1.00
6–8	1.18
9–11	1.25
12 or more	1.33

(*Source: Manual of Uniform Traffic control Devices,* Draft, Federal Highway Administration, Washington DC, December 2007, Table 4C-2.)

Summary:

It is important to reiterate the basic meaning of these warrants. No signal should be placed without an engineering study showing that the criteria of at least one of the warrants are met. However, meeting one or more of these warrants does not necessitate signalization. Note that every warrant uses the language "The need for a traffic control signal shall be considered. ..." (Emphasis added). Although the "shall" is a mandatory standard, it calls only for consideration, not
also convince the traffic engineer that installation of a signal will improve the safety of the intersection, increase the capacity of the intersection, or improve the efficiency of operation at the intersection before the signal is install That is why the recommended information to be collect during an "engineering study" exceeds that needed to simply) apply the nine warrants of the MUTCD. In the end engineering judgment is called for, as is appropriate in a professional practice.

Table 12: Adjustment Factor for High-Occupancy Buses

% of High-Occupancy Buses* on Minor-Street Approach	Adjustment Factor
0%	1.00
2%	1.09
4%	1.19
6% or more	1.32

*20 or more persons per bus.

(*Source: Manual of Uniform Traffic control Devices,* Draft, Federal Highway Administration, Washington DC, December 2007. Table 4C-3.)

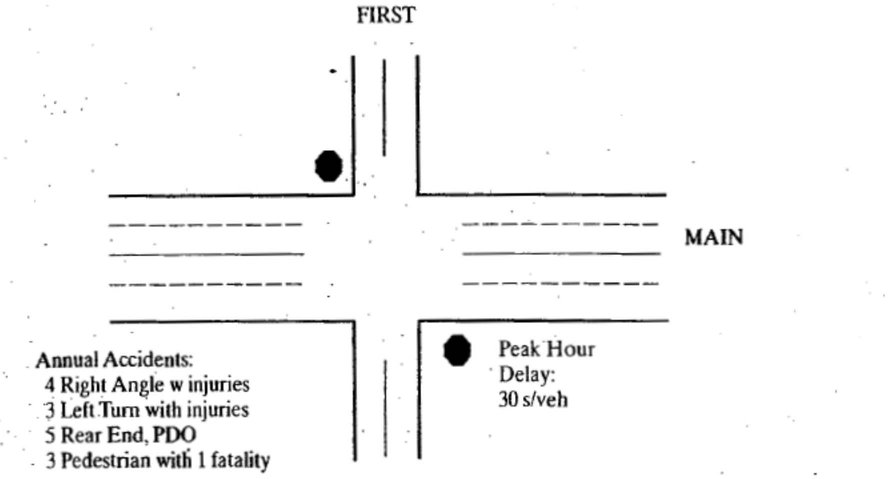
Table 13: Adjustment Factor for Tractor Trailer Trucks

% of Tractor-Trailer Trucks on Minor-Street Approach	Adjustment Factor	
	D Less Than 70 ft	D of 70 ft or More
0%–2.5%	0.50	0.50
2.6%–7.5%	0.75	0.75
7.6%–12.5%	1.00	1.00
12.6%–17.5%	2.30	1.15
17.6%–22.5%	2.70	1.35
22.6%–27.5%	3.28	1.64
More than 27.5%	4.18	2.09

(*Source: Manual of Uniform Traffic control Devices,* Draft, Federal Highway Administration, Washington DC, December 2007, Table 4C-4.)

A sample Problem in Application of Signalized Warrants

Consider the intersection and related data shown in Figure 11. Note that the data are formatted in a way that is conducive to comparing with warrant criteria. Thus a column adding the traffic in each direction on the major street is included, and a column listing the "high volume" in one direction on the minor street is also included. Pedestrian volumes are summarized for those crossing the major street because this is the criterion used in the pedestrian warrant. As you will see, not every warrant applies to every intersection, and data for some warrants are not provided. The following analysis is applied:



Time	Main Street Volume (veh/h)			First Ave Volume (veh/h)			Ped Volume (ped/h)
	EB	WB	TOT	NB	SB	High Vol	Xing Main
11 AM–12	400	425	**825**	75	80	**80**	115
12–1 PM	450	465	**915**	85	85	**85**	120
1–2 PM	485	500	**985**	90	100	**100**	125
2–3 PM	525	525	**1,050**	110	115	**115**	130
3–4 PM	515	525	**1,040**	100	95	**100**	135
4–5 PM	540	550	**1,090**	90	100	**100**	140
5–6 PM	550	580	**1,130**	110	125	**125**	120
6–7 PM	545	525	**1,070**	96	103	**103**	108
7–8 PM	505	506	**1,011**	90	95	**95**	100
8–9 PM	485	490	**975**	85	75	**85**	90
9–10 PM	475	475	**950**	75	60	**75**	50
10–11 PM	400	410	**810**	50	55	**55**	25

Figure 11: Intersection and Data for Sample Problem in Signal Warrant

Warrant 1:
There is no indication that the 70% reduction factor applies, so it is assumed that either Condition A or Condition B must be met at 100%, or both must be met at 80%. Condition A requires 600 veh/h in both directions on the multilane major street and 150 veh/h in the high-volume direction on the one-lane minor street. Although all 12 hours on the major street shown in Figure 18.11 have

more than 600 veh/h (total, both directions), none have a one-way volume equal to or higher than 150 veh/h on the minor street. Condition A is not met. Condition B requires 900 veh/h on the major street (both directions) and 75 veh/h on the minor street (one direction). The 10 hours between 12:00 noon and 10:00 pm meet the major-street criterion. The same 10 hours meet the minor-street criterion as well. Therefore, Condition B is met. Because one condition is met at 100%, the consideration of whether both conditions are met at 80% is not necessary.

Warrant 1 is satisfied.

Warrant 2:

Figure 12 shows the hourly volume data plotted against the four-hour warrant graph. The center decision curve (one street with multilane approaches, one with one-lane approaches) is used. Only one of the 12 hours of data is above the criterion. To meet the warrant, four are required. The warrant is not met.

Warrant 3:

Figure 13 shows the hourly volume data plotted against the peak-hour volume warrant graph. Again, the center decision curve is used. None of the 12 hours of data is above the criterion. The volume portion of this warrant is not met.

The delay portion of the peak-hour warrant requires 4 vehicle-hours of delay in the high-volume direction on a STOP-controlled approach. The intersection data indicate that each vehicle experiences 30 seconds of delay. The peak one-direction volume is 125 veh/h, resulting in 125 * 30 = 3,750 veh-secs of aggregate delay, or 3,750/3,600 = 1.04 veh &s of delay. This is less than that required by the warrant. The delay portion of this warrant is not met.

Warrant 4:

This warrant includes both a four-hour criterion and a peak-hour criterion, only one of which must be met to satisfy it. Figure 14 illustrates the solution. The four-hour pedestrian warrant is met, and the peak-hour pedestrian warrant is not met. Because only one condition must be satisfied, the pedestrian **warrant is met.**

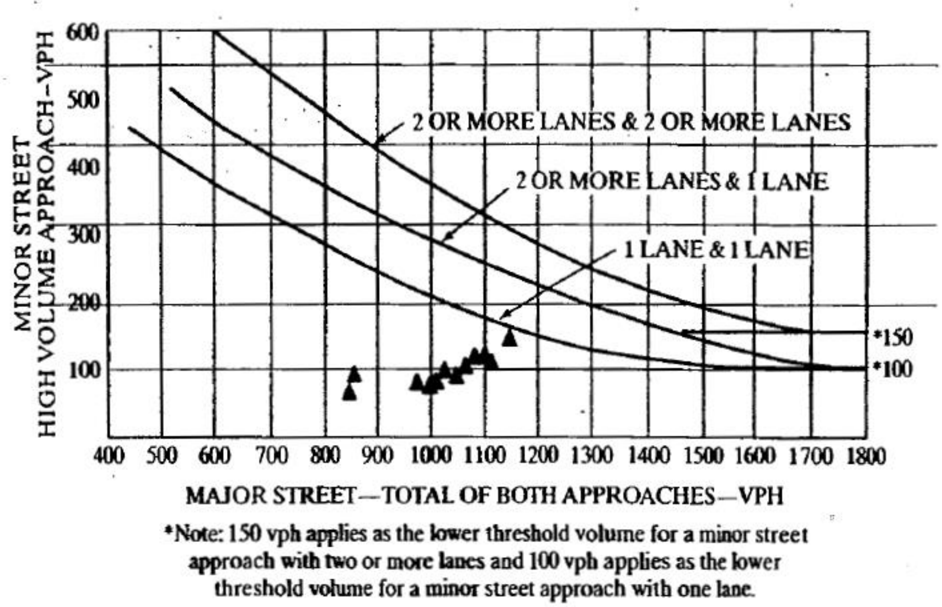
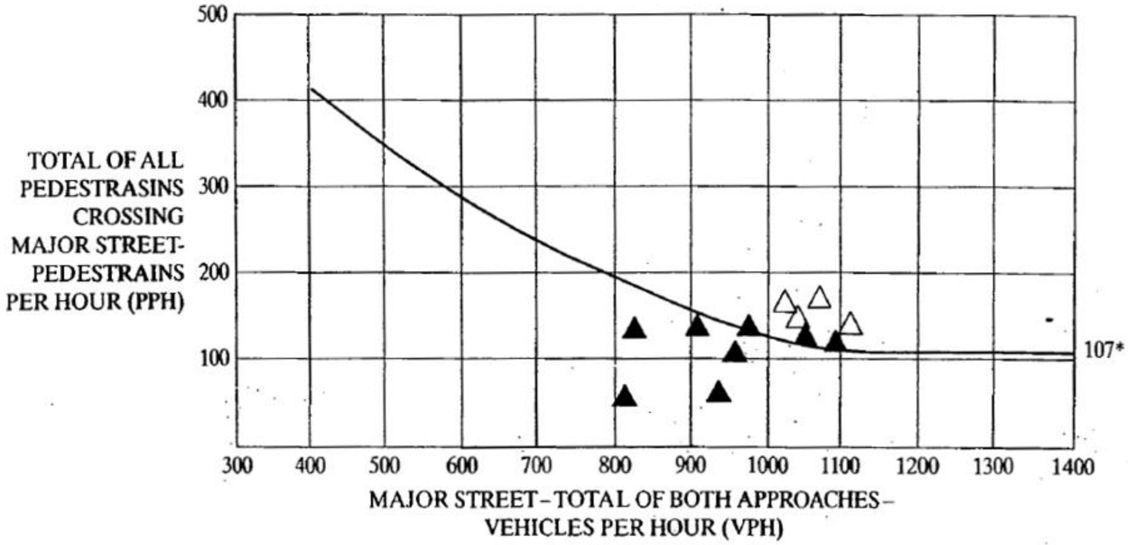
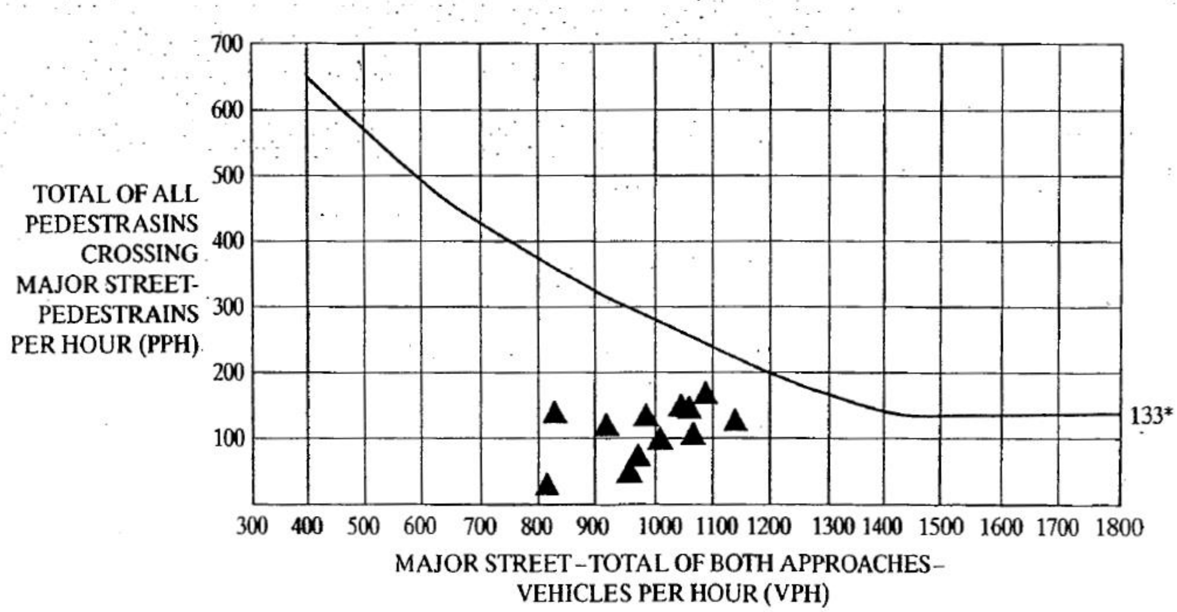


Figure 13: Example Application of Warrant 3



*Note: 107 pph applies as the lower thershold volume.

(a) Four-Hour Pedestrian Warrant



*Note: 133 pph applies as the lower thershold colume.

(b) Peak-Hour Pedestrian Warrant

Figure 14: Example Application of Warrant 4

Warrant 5:
The school-crossing warrant does not apply. This is not a school crossing.

Warrant 6:
No information on signal progression is given, so this warrant cannot be applied.

Warrant 7:

The crash experience warrant has several criteria: Have lesser measures been tried? Yes, because the minor street is already STOP-controlled. Have five accidents susceptible to correction by signalization occurred in a 12-month period? Yes-four right-angle, three left-turn, and three pedestrian. Are the criteria for Warrants 1A or 1B met to the extent of 80%? Yes, Warrant 1B is met at 100%. Therefore, the **crash experience warrant is met**.

Warrant 8:

There is no information given concerning the roadway network, and the data reflect an existing situation. This warrant is not applicable in this case.

Warrant 9:

Because this situation is not a highway-rail grade crossing location, this warrant does not apply.

In summary, a signal should be considered at this location because the criteria for Warrants 1B (Interruption of Continuous Traffic), 4 (Pedestrians), and 7 (Crash Experience) are all met unless unusual circumstances arc present, it would be reasonable to expect that the accident experience Will improve with signalization, and it is, therefore, likely that one would be placed.

The fact that Warrant IB is satisfied may suggest that a semiactuated signal be considered. In addition. Warrant 4 requires the use of pedestrian signals, at least for pedestrians crossing the major street. If a semiactuated signal is installed, it must have a pedestrian pushbutton (for pedestrians crossing the major street). The number of left-turning accidents may also suggest consideration of protected left-turn phasing, although this would not be done if a semiactuated signal is used.