Mn/DOT Access Management Guidelines

Background Technical Report

Access Operations Study:

Intervening Access Analysis - Gaps

December 2002

Minnesota Department of Transportation

Office of Investment Management

Access Management Unit

Study Overview

Summary Overview

The Access Category System and Spacing Guidelines (Technical Memorandum No. 02-10-1M-01) were developed to provide a recommended spacing for full-movement public intersections (also referred to as primary intersections in the Guidelines). The spacing of primary intersections is greatly influenced by the desire to develop good traffic progression through a series of coordinated traffic signals. In urban/urbanizing areas it is assumed that every public intersection has the potential of being signalized; therefore, the uniform spacing of intersections is critical to developing progression. It is also assumed that a supporting street network either exists or is planned within urbanizing areas, so property along the highway has the potential for alternate access. On the other hand, in rural areas neither signalized intersections nor a supporting street network is anticipated. The rural highway in many cases will be the only road serving the area, both for mobility as well as for accessibility.

Without the emphasis on maintaining uniform signal spacing, rural highway intersection spacing is influenced by traffic safety, roadway geometrics, existing topography and reasonable accessibility. Using these criteria, rural primary intersection spacing was set up at either one mile for principal arterials or one-half mile for minor arterials and collectors. On divided highways, these are the full-movement intersections where median openings will be located. In many cases, the factors listed above (roadway geometrics, existing topography and reasonable accessibility) also make it necessary to construct additional (or secondary) public intersections.

The Guidelines define secondary intersections as public intersections located halfway between two primary full-movement intersections. The intent of secondary intersections is to promote the consolidation of private entrances into a single low volume public intersection. The secondary intersection is intended to operate without causing a significant impact to the safety and operations of the highway. If a secondary intersection were to meet signal warrants, actions would be taken to limit turn movements, close the intersection or take other measures to eliminate the need for signalization.

As mentioned previously, the allowance for secondary intersections is governed by several factors, but one of the key factors, safety, is not readily apparent. The purpose of this study was to look at the safety aspects of secondary intersections and develop a process to evaluate when they should be allowed and under what conditions.

Study Results

A literature search showed that the potential risk of a crash occurring at an intersection or private driveway is related to the mainline traffic volume, the volume of traffic using the access point, roadway geometrics and driver behavior.

This study looked primarily at the correlation between the available gaps between vehicles on the mainline and demand for these gaps from the cross street traffic. As the availability of gaps decreased, or as the demand for gaps increased, drivers on the cross street were more willing to accept smaller gaps, thereby increasing the risk of a crash. The study took a conservative approach by analyzing the worst-case scenario – the left-turn movement from the cross street on to the highway.

Based on this analysis, three graphs were developed to identify the conditions for when an access point may present a high risk conflict potential. The graphs represent the three primary highway cross-sections found in the state: two-lane undivided, four-lane divided with narrow medians and four-lane divided with wide medians. These graphs compare the opposing traffic volumes with the cross street traffic volume entering the intersection.

This study looked primarily at rural intersections and recognized the following assumptions:

- Traffic from adjacent intersections does not interfere with the operations of the study location,
- The highway corridor is not signalized; traffic on the mainline arrives at random intervals and does not travel in platoons,
- There is sufficient geometry on the cross streets to allow a separate lane for each minor street movement, and
- The presence of slow-moving and heavy vehicles is considered.

Implications for Access Management Guideline Applications

Based on the findings of this study, MnDOT's Access Management Guidelines permits secondary intersections halfway between primary full-movement intersections under certain conditions:

- Secondary full-movement intersections are permitted on rural two-lane highways if the 20-year forecasted traffic volumes do not yield a high risk conflict potential.
    - *The existence of a new intersection will not create significant impact to the operations or safety of the highway.*
    - *Figure 7 in the Access Management Guidelines is used.*
- Secondary full-movement intersections are permitted on urban/urbanizing two-lane highways if the 20-year forecasted traffic volumes do not yield a high risk conflict potential.
    - *This assumes that the highway corridor is not part of a coordinated signal system. Generally, once a highway corridor reaches the point of having coordinated traffic signals, it is also carrying enough traffic to be a four-lane divided highway. If a two-lane highway corridor is part of a coordinated signal system, a new secondary intersection should not be permitted unless it can be constructed as right-in/right-out only.*

    - *Otherwise, the existence of a new intersection will not create significant impact to the operations or safety of the highway.*

    - *Figure 7 in the Access Management Guidelines is used.*

- Secondary full-movement intersections are permitted on rural four-lane highways if the 20-year forecasted traffic volumes do not yield a high risk conflict potential.

    - *The existence of a new intersection and median opening will not create significant impact to the operations or safety of the highway.*

    - *Figure 8 or 9 in the Access Management Guidelines is used depending on the median width.*

- Secondary right-in/right-out (RIRO) only intersections are permitted on rural four-lane highways if the 20-year forecasted traffic volumes yield a high risk potential for a full-movement intersection, but yield a low risk conflict potential for a right-in/right-out only intersection.

    - *In this case, a new intersection would create a significant impact if there were a median opening, but would not create significant impact to the operations or safety of the highway if the intersection were limited to right-in/right-out only.*

    - *Figure 8 and 9 in the Access Management Guidelines is used depending on the median width.*

    - *Figure 8 in the Access Management Guidelines is used when looking at the risk potential of a right-in/right-out only intersection.*

- Secondary full-movement intersections are not permitted on urban four-lane highways. Secondary right-in/right-out intersections may be permitted on urban four-lane highways.

    - *Traffic progression along a coordinated signal system would never provide sufficient gap at the location of the secondary intersection, but would provide sufficient gap for a right-in/right-out intersection.*

    - *Under these conditions the gap analysis procedure do not need to be used.*

- Low-volume private entrances (access types 1 and 2) are permitted on rural two-lane highways if the 20-year forecasted traffic volumes do not yield a high risk conflict potential.

    - *The gap analysis procedure was expanded to test the risk conflict potential of rural low-volume private entrances. In these cases, private entrances may be permitted if they do not create significant impact to the operations or safety of the highway.*

    - *Figure 7 in the Access Management Guidelines is used.*

ACCESS OPERATIONS STUDY

INTERVENING ACCESS ANALYSIS – GAPS

Prepared for
Mn/DOT OIM

Prepared by
SRF Consulting Group, Inc.

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The *Access Operations Study* is intended to assist Mn/DOT in refining access spacing guidelines as they relate to intervening access in rural areas. To investigate these issues, information from technical engineering manuals was reviewed and summarized, experience from past projects was applied, and a operations' model was used to confirm delays and level of service of side-streets.

I. Intervening Access Points in Rural Areas

Problem Statement: *Mn/DOT had developed draft access spacing guidelines. These guidelines had gone through much review and discussion and they covered a broad range of facilities and conditions. However, there was one particular issue that needed additional guidance. This issue concerned intervening access points in rural areas (categories 2A, 3A, and 5A). The draft guidelines identified full-access spacing in these categories as well as rules for allowing intervening access at the mid-point locations. However, there was a lack of consensus on whether intervening access should be allowed under all circumstances and whether movements at the mid-point access should be restricted. Mn/DOT sought additional criteria and background information that would assist it developing consensus on this issue as well as tools for personnel to utilize in making field decisions.*

Background – Previous Methodology

The original approach to intervening access points looked at whether or not the potential access point would meet signal warrants as defined in the MUTCD. The intent of this approach was to avoid constructing new intersections that would add signals along rural corridors or add new signalized intersections that would hinder mainline progression. This approach was based exclusively on the magnitude of the side street volume (2,500

ADT). This volume was thought to be low enough to avoid triggering potential signal warrants.

However, some felt that this threshold did not provide sufficient flexibility. For example, in areas that have very low mainline volumes, this policy was thought to be too restrictive. In areas of high mainline volumes, they were thought to be not restrictive enough (i.e. potentially midpoint access could warrant a signal with side street volumes of 2,500). In addition, a concern was raised with respect to the weaving maneuver that would be required between the right-in/right-out access point and a downstream U-turn movement. As a result of these comments, additional investigation and analysis was undertaken to improve the policy criteria being used.

Revised Methodology

The new methodology needed to relatively easy to use and understand and it needed to be more flexible so that it was more restrictive in areas where signals and operating problems may exist and less restrictive in areas where operational problems where unlikely.

The methodology that was selected and discussed in the following paragraphs is founded on human behavior and driver decision-making. The driving task encompasses and number of activities from physical steering of the vehicle, identifying where to go (what path to follow in accordance with signing, and roadway conditions), and basic navigation or trip planning. Throughout the driving task, drivers process numerous bits of information in order to make decisions. They make some decisions immediately and delay others based on judgment, estimation, and prediction gained through experience. As the complexity of decisions increase (higher volumes), more time is required to process the information and make a judgment. As the decision time increases so does the chance for error.[1]

In high-volume areas with numerous potential conflicting vehicles, vehicle delays tend to increase and longer queues are experienced. As wait times increase, it has been demonstrated that drivers get impatient and will take more risks (drivers will accept a shorter gap in the mainline flow). In fact, a detailed study on vehicle gap acceptance showed that the minimum acceptable gap was reduced by about 20 percent as delay increased from zero to approximately 90 seconds.[2] In low-volume areas, there will be fewer conflicting vehicles and very little delay. As a result the decision-making process and judgment requirements in these areas are less complex.

While there are a number of factors to consider in terms of allowance of intervening side street access, the factor that was focused on in this study was the ability for side street traffic to find adequate gaps in mainline flows. A gap is defined as the minimum time interval in the major-street traffic stream that allows intersection entry for one minor-

[1] Highway Capacity Manual 2000
[2] A Further Investigation on Critical Gap and Follow-up Time; Transportation Research Circular E-CO18: 4th International Symposium on Highway Capacity.

street vehicle. The critical gap is defined as the minimum gap (time in seconds) that would be accepted by the average driver (50 percent of the drivers would reject gaps that were shorter and 50 percent would accept gaps greater or equal to the critical gap).[3]

Because delays and risk-taking are both a function of mainline volumes and side street volumes, it was felt that a methodology could be developed that would categorize access locations with respect to their operational function (relates function in terms of providing drivers with sufficient gaps in mainline flow to accommodate the peak hour demand of the side street). The policy would then focus on being more restrictive of accesses in areas with insufficient gaps, and less restrictive in areas where the number of gaps is adequate. As a result, a tool was developed to assist road authorities in identifying potential high-risk areas (areas with limited gaps). This tool could be used to help focus its access strategies towards high-risk areas.

Analysis of Available Gaps

To assess the availability of gaps and side street capacity issue, information from the Highway Capacity Manual 2000 (HCM) was used. Chapter 17 from this manual provides a technical analysis of unsignalized intersections and their side street capacity. The capacity is based on a number of factors including the type of side street movement, approach grades, critical gap, flow-up time, percentage of heavy vehicles for minor movement, and adjustment for wide median.

HCM formula (17-3) was used to calculate side street capacities for four-lane narrow median facilities (assumed single-stage crossing with no median storage) and HCM formula (17-32) was used for four-lane wide-median roadway (assumed two-stage crossing with two car storage in median area). A narrow median can't provide sufficient space for vehicles to sit between the through lanes and as a result vehicles accessing the route from a side street have to find a gap in both directions before making a left or through movement. In contrast to a narrow median, a wide median provides sufficient space for vehicles (generally limited to autos) to sit between through lanes. As a result, vehicles trying to access from the side street can cross one direction at a time (only need to find a gap in one direction at a time). Because two-stage crossings divide the crossing maneuver into two steps, there are fewer conflicts that one has to contend with at one time. As a result, two-stage crossings are more efficient (can accommodate higher volumes) than single-stage crossings.

Caution should be used in applying two-stage crossing results. Two-stage crossings are generally limited to analyzing side street auto movements not trucks. Most rural four-lane facilities in Minnesota have insufficient median spacing for the storage of trucks. As a result, one should consider the types of vehicles using the side street approaches and if these movements have a significant portion of trucks a narrow median crossing analysis should be used.

[3] Highway Capacity Manual 2000

Four-lane Analysis Process

Based on different levels of mainline flow (conflicting volume), side street capacity movements were calculated, using Highway Capacity Manual (HCM) equations and plotted for the four-lane facilities. The results are shown on Figures 1 and 2. These figures closely conform to exhibits 17-7 in the HCM.

These figures were broken into two general areas. The lighter areas in these figures (low-risk) indicate that sufficient gaps should be available in the major-street flow during peak hours to adequately accommodate the magnitude of the minor-street volumes. Darker areas (high-risk) indicate that a combination of minor-street and major-street volumes are close to or exceed capacity. This will likely contribute to additional minor-street delays, longer queues and drivers taking shorter gaps (safety problems). It should be noted that daily volumes were added to these figures to make them easier to use for planning-level analysis[4].

As an additional check on where the boundaries were drawn (line between low- and high-risk areas), individual intersection capacity analysis was completed for different conflicting volume combinations using Highway Capacity Software (HCS). This analysis provided average delays for side street vehicles (seconds). These were plotted on the figures and were used to confirm levels of service for a range of combinations. Generally, these boundaries follow the area between LOS E/F and are shown in Appendix A.

Two-lane Analysis Process

The HCM also provided a figure for two lane roadways (exhibit 17-6). When comparing the two-lane figure, exhibit 17-6 in the HCM, with the four-lane narrow-median figure, exhibit 17-7; there was virtually no difference between these figures in terms of minor-street movement capacity. This did not seem to make sense, since a four-lane facility should provide additional gaps in traffic flow, given the additional travel lanes and the ability of vehicles to be coincident with one another. As a result, SRF set up an operations model using VISSIM and tested the minor-street movement capacity for a rural two-lane intersection using the same gap assumptions used by HCM (Appendix B). The results of this analysis indicated lower side street capacities than shown in HCM exhibit 17-6. This result seemed more consistent with field experiences and it was more consistent with input from the studies technical group. As a result, the VISSIM model results were used to develop Figure 3 (two-lane analysis).

[4] The daily volume was determined based on the assumption that 10 percent of the daily volume occurs in the peak hour.

Figure 1: Four lane (narrow median)

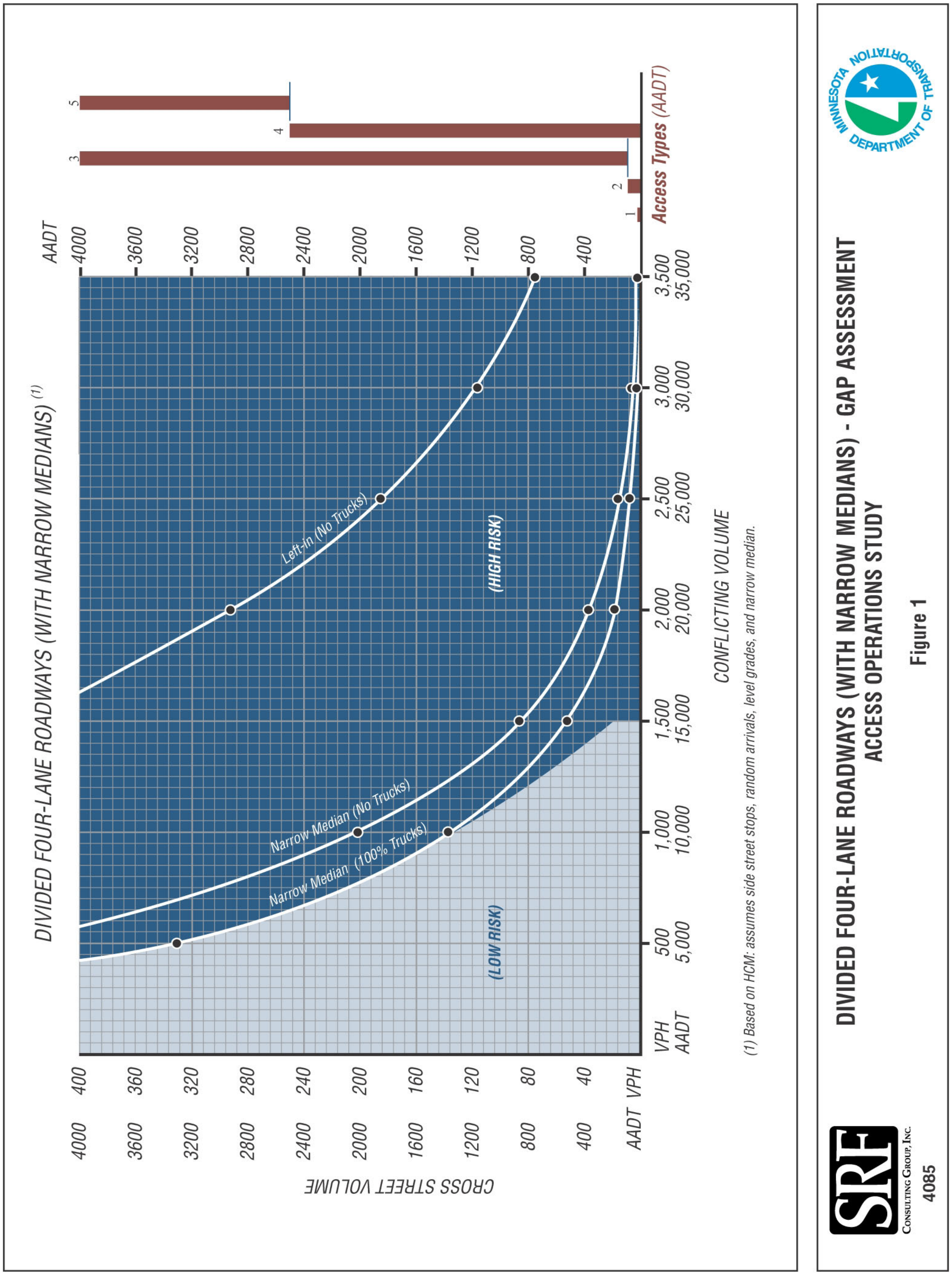


Figure 2: Four lane (wide median)

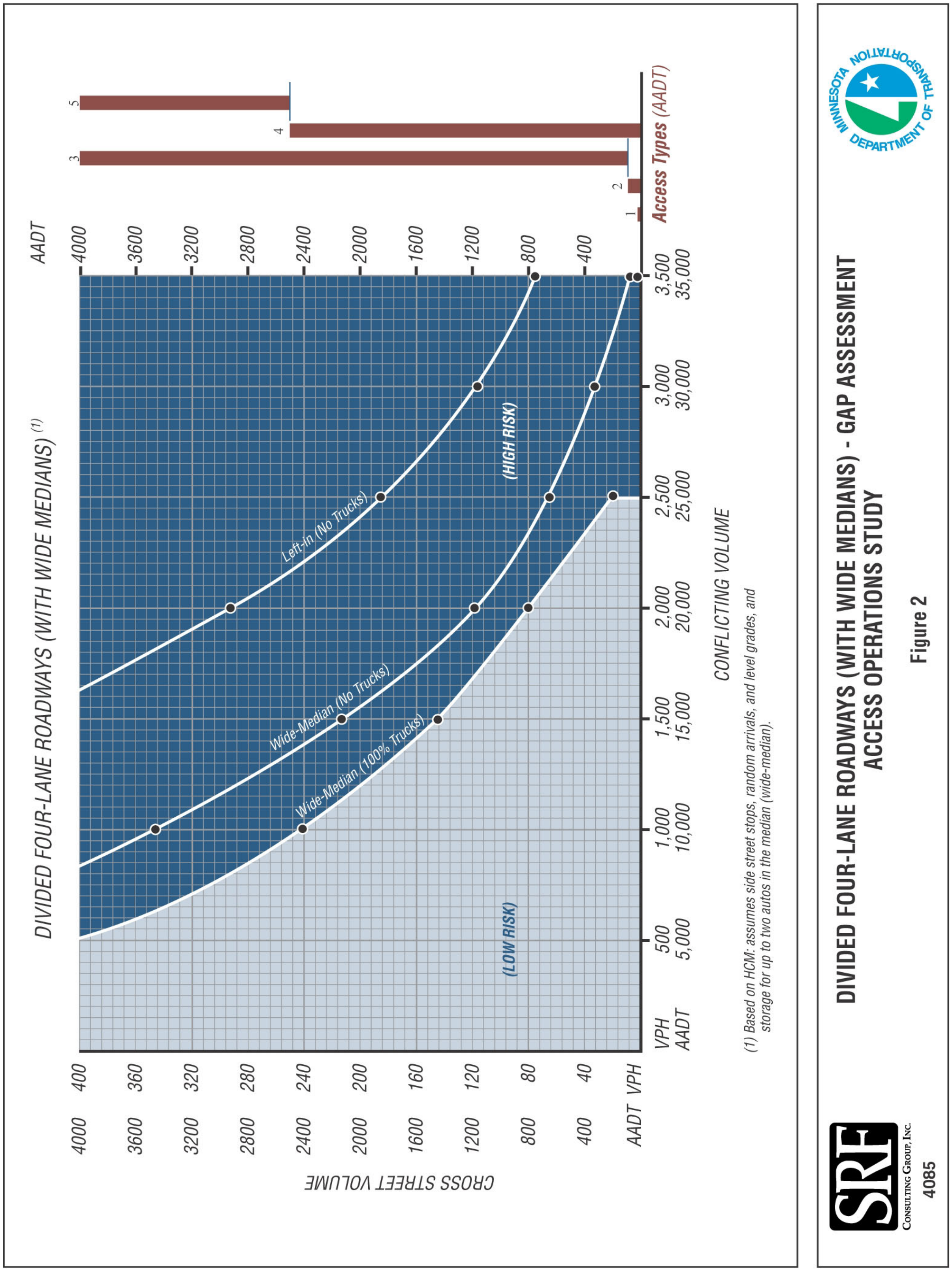
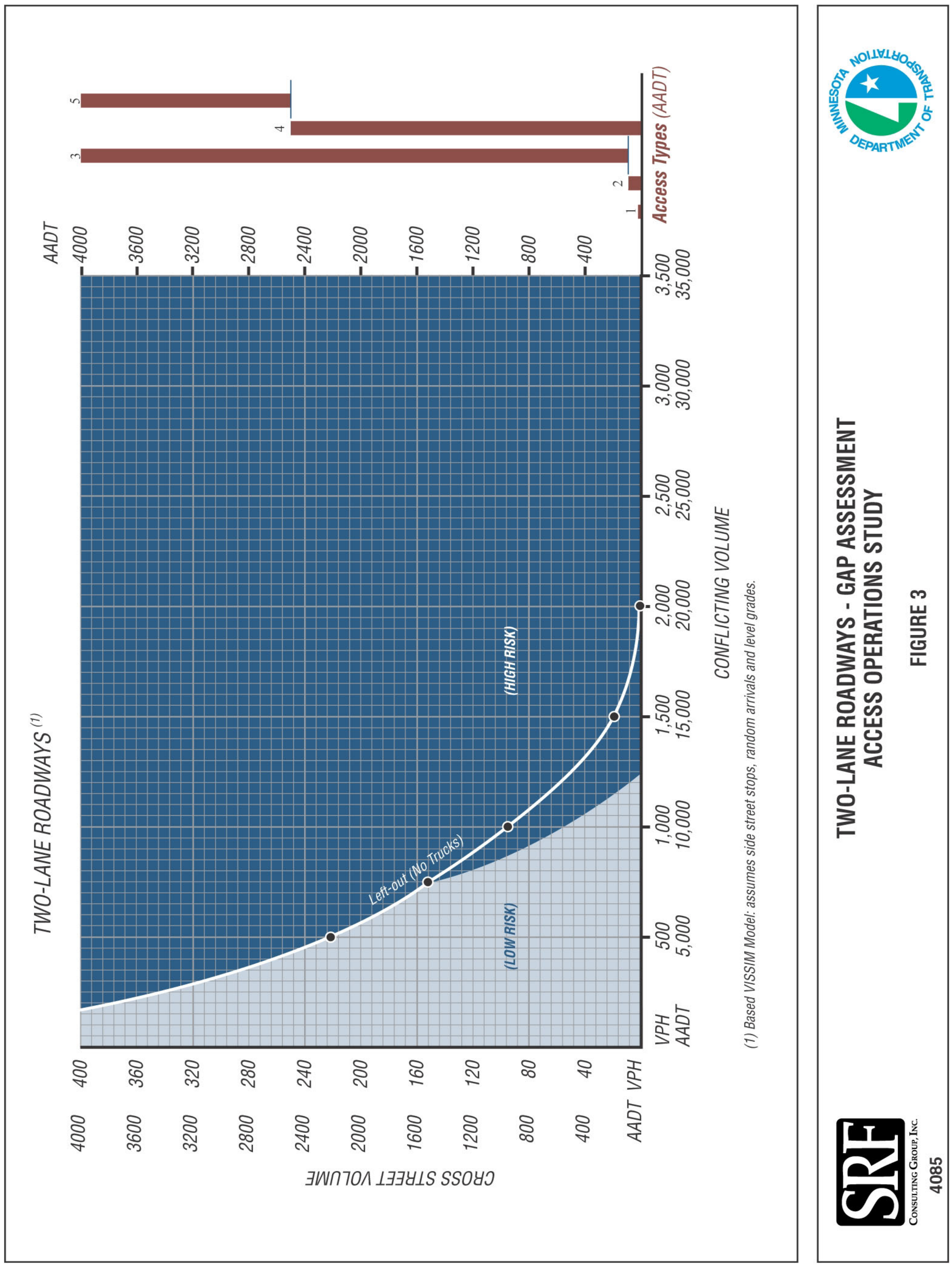


Figure 3: Two Lane



When using these minor-street movement capacity figures to assess the potential operational characteristics of intersections <u>the following should be kept in mind:</u>

a. The following base conditions are assumed in the gap analysis:

   ✓ Traffic from nearby intersections does not back up into subject intersection

   ✓ A separate lane is provided for each minor-street movement (or sufficient lane geometry is provided at the approach so that the intersection functions as if it had separate lanes for each movement)

   ✓ An upstream signal does not affect the arrival pattern of the major-street movement (assumes random arrivals)

   ✓ Higher order conflicting movements (major street through movements from left, major-street right turns from left, and major-street left turns from right) operate in queue free state (uncongested). If higher order movements become congested it affects lower-priority movements.

b. **One should pay special attention to the fact that the horizontal axis in the chart is <u>not only the major-street volume</u>, but the <u>total conflicting volume</u> to the minor-street movement**. For example, left-turn out of a side street approach, conflicts with both major-street through movements, as well as left-turns off the major-street and the opposing minor-street through movements. The Highway Capacity Manual provides guidance in Exhibit 17-4 on how to account for conflicting volumes. This is provided in Appendix B.

c. If the facility has significant fluctuations in traffic volumes, one should consider summer weekday and recreational volumes if they represent a significant operational period for that facility. One can use the following:

   ✓ Volumes on most of Minnesota's corridors fluctuate throughout the year (January is the low month and July-August are the high months) with summertime volumes usually10 to25 percent above average annual daily volumes. Recreational peak can vary from 25 percent to 60 percent higher than AADT.

   ✓ In some cases, corridors may have extremely <u>unbalanced flows</u> or have <u>significantly higher peak hours (</u>Peak hours can go as high as 14 to 17 percent of the AADT in recreational type corridors or on holidays). **If you need to account for this, peak hour counts should be taken**. In absence of normal peak hour information, one may assume that the peak hour volume is 8 to10 percent of the average annual daily volume (AADT).

d. The type of users should also be considered. The shaded areas shown assume two-percent trucks (side street volume). If higher percentage of trucks is assumed there will be fewer gaps available.

e. The analysis assumed that approach grades were level. Uphill grade would negatively affect side street capacity (higher risk would occur at lower volumes).

f. The analysis should not be applied to signalized corridors that potentially have platoon type flow. Signalized corridors should be analyzed using additional field data or by using analysis packages that can account for the different impacts of signal timing and phasing as well as platoon arrivals.

Findings – Intervening Access Rural Areas - Gap Analysis

There are a number of findings and general observations that were noted based on this analysis. These are summarized below:

1. At first glance, the HCM exhibits (17-6 and 17-7) show there is very little difference between the minor-street capacity for left turns, through movements and right turns. At high conflicting volumes, the graphed lines (differences) are indistinguishable from one another. At lower conflicting volumes the differences range up to 20 percent. **However, the right turn movements have different significantly less conflicting volumes (usually about 50 percent less). The minor-street left has nearly twice the conflicting flow as the right-turn out for the same location or intersection (right-turn only conflicts with vehicles approaching from left); therefore, the capacity for minor street lefts and through movements is significantly less than right-turns.**

2. There is a significant difference in the type of conflict between minor-street lefts and through movements, and right turns. Minor-street right turns generally result in rear-ends and sideswipe type crashes. These crashes are less severe than right-angle type crashes that can occur due to the crossing movements required from left turns and through movements. In addition, minor street right turns have the option of using the shoulder as a merge lane to gain access during busy times where the other movements have no similar option. On four-lane facilities, the right turn is also being made into the slower speed traffic lane whereas the left turn is being made into the high-speed traffic lane.

3. A Florida Department of Transportation Study determined that on six-lane arterials with large traffic volumes, high speeds and high minor street or entrance volumes, the right-turn movement and a downstream U-turn movement leads to a statistically significant reduction in crashes as compared to direct left turns from minor street. Four lane routes were also studied but the sample was too small to draw conclusive results.

4. Four-lane facilities that have volumes over 30,000 will have very few gaps of an acceptable length during peak hours (5 gaps or one per 12 minutes). This means that the major street isn't able to accommodate minor-street movements without long delays, even for very low volume access points.

5. There are substantial capacity advantages <u>between</u> lefts off of the major-street (lefts-in) and movements on to the major street from the minor street approaches. Figure 2 shows that for the same number of conflicts (i.e. 1,500 vph) the capacity for lefts-in (LT Major = 460 vph), whereas the capacity for lefts-out is 85 vph). This suggests that consideration be given to allowing major-street lefts under special conditions. Conditions where major-street lefts may be advantageous include:

   ✓ Intervening left-in would relieve problems at downstream intersection including - high volume of lefts require additional turn lanes, and/or lefts require take too much of the cycle time limiting time available to through band. In some cases, other states have even signalized some of the intervening left-in intersections. These signals can be coordinated with upstream signals so that they don't affect the green band for the major-street.

   ✓ Intervening left-in movements can provide better business circulation and may be more acceptable in negotiating access changes where facility is being retrofitted. In addition, removing lefts at major street intersections also would remove traffic from local frontage road intersections, which at times are in close proximity to the major-street intersections. This can also have a positive benefit to overall operations.

6. Significant consideration should always be given to access consistency. If the facility in question has historically allowed access for only public streets and all other private access is right-in-right-out, this should be given significant weight in addressing new access requests. In addition, if a corridor vision has been established, access policies should conform to that vision

Appendix A

Side Street Level of Service Computations

Level of Service Thresholds for Unsignalized Intersections (seconds of delay per vehicle):

LOS A	<10
LOS B	>10 and <15
LOS C	>15 and <25
LOS D	>25 and <35
LOS E	>35 and <50
LOS F	>50

The following analyses were performed using the Highway Capacity Software for two-way stop controlled intersections. The mainline through volume was assumed to have a 50/50 directional split. One cross-street left-turn movement was assigned the crossing left-turn volume. All other movements were assumed to be zero.

Table 1
Two-Lane Undivided Roadway

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
500	140	16.4	C
500	260	23.4	C
1,000	50	28.6	D
1,000	95	38.5	E
1,000	140	58.1	F
1,000	200	119.9	F
1,250	20	36.5	E
1,250	50	47.5	E
1,250	90	77.5	F
1,500	5	47.8	E
1,500	20	57.5	F
1,500	50	91.1	F
1,500	90	197.3	F
2,000	20	182.6	F

Note: Assumes two percent trucks for cross-street left-turn movement.

Table 2
Four-Lane Divided Roadway (No Median Storage)

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
500	140	14.1	B
500	260	18.3	C
1,000	50	20.7	C
1,000	140	31.0	D
1,000	200	47.8	E
1,250	20	24.9	C
1,250	50	28.9	D
1,250	90	37.4	E
1,500	20	34.0	D
1,500	50	43.1	E
1,500	90	66.9	F
2,000	20	71.9	F

Note: Assumes two percent trucks for cross-street left-turn movement.

Table 3
Four-Lane Divided Roadway (No Median Storage), 100% Trucks

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
500	140	21.9	C
500	260	41.0	E
1,000	50	38.9	E
1,000	140	112.9	F
1,000	200	243.8	F
1,250	20	48.7	E
1,250	50	71.2	F
1,250	90	141.7	F
1,500	20	80.0	F
1,500	50	150.0	F
1,500	90	344.8	F
2,000	20	293.1	F

Note: Assumes 100 percent trucks for cross-street left-turn movement.

Table 4
Four-Lane Divided Roadway (Median Storage for One Car)

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
1,500	40	21.3	C
1,500	210	63.9	F
2,000	40	31.4	D
2,000	120	63.2	F
2,500	20	40.5	E
2,500	40	49.3	E
2,500	65	66.5	F
3,000	20	61.6	F
3,000	35	76.8	F
3,500	10	78.1	F

Note: Assumes two percent trucks for cross-street left-turn movement.

Table 5
Four-Lane Divided Roadway (Median Storage for Two Cars)

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
1,500	40	18.5	C
1,500	210	41.5	E
2,000	40	25.9	D
2,000	120	43.4	E
2,500	20	33.1	D
2,500	40	38.4	E
2,500	65	48.0	E
3,000	20	48.7	E
3,000	35	57.7	F
3,500	10	63.8	F

Note: Assumes two percent trucks for cross-street left-turn movement.

Table 6
Four-Lane Divided Roadway (Median Storage for Two Cars), 100% Trucks

Mainline Through Volume	Crossing Left-Turn Volume	Delay of Crossing Left-Turn (sec/veh)	LOS of Crossing Left-Turn
1,000	40	20.1	C
1,000	210	53.0	F
1,500	40	32.2	D
1,500	210	211.0	F
2,000	40	58.1	F
2,000	120	213.3	F
2,500	20	83.2	F
2,500	40	127.1	F
2,500	65	225.5	F
3,000	20	162.7	F
3,000	35	253.6	F
3,500	10	236.7	F

Note: Assumes 100 percent trucks for cross-street left-turn movement.

Appendix B

Gap Assumptions

Addendum

Mn/DOT Supplemental Information

Technical Review of Gap Analysis

The question to be answered is if gap times of 8.1 and 8.5 seconds (as used by SRF in the development of the graphs to be used in the Access Spacing Guidelines) are sufficient given that current Mn/DOT intersection sight distance criteria is based on a longer time measurement. Initial concerns were that the gap times of 8.1 and 8.5 seconds were less than the general rule of thumb used for intersection sight distance (10 seconds); therefore promoting a situation that might adversely impact the safety and operations of the major roadway. To address this, we first looked at the definitions of the measures in question:

- Intersection Sight Distance (ISD) is the unobstructed viewing distance a driver at or approaching an intersection should have to proceed safely to cross or turn onto a major roadway without causing the mainline traffic to reduce speed to less than the running speed of the roadway. Intersection sight distance is measured vehicle approaching on the major roadway to the centerline of the intersecting side street. Depending on the type of maneuver being performed by the driver on the side street, the intersection sight distance will vary. The Mn/DOT Road Design Manual criterion is based on the 1990 and 1994 AASHTO Green Book.

- The Critical Gap is the measure of time between successive vehicles on the major roadway. The critical gap is the average time at which a driver on a side street is willing to cross or turn onto a major roadway. It is generally measured in studies as the time between successive vehicles on the major roadway crossing the centerline of the intersecting side street. The critical gap may be between vehicles traveling in the same direction, or in opposite directions on the major roadway.

As indicated in the definitions above, intersection sight distance is a measure of distance, where the critical gap is a measure of time. While they may be translated into the same units of measure, they cannot be easily compared. The intersection sight distance represents an unobstructed line of sight long enough for a driver to perceive an approaching vehicle and then react accordingly. The critical gap is measured, assuming the driver already perceives the situation and is merely waiting to react. It can be seen as a measure of driver's judgment of the situation. The difference between sight distance and the critical gap can be looked at as follows:

> *An average driver on the side street may see several vehicles within the unobstructed intersection sight distance and if any two of the vehicles are separated by the critical gap or longer, the driver will cross or turn onto the major roadway. If the intersection sight distance allows the driver to see multiple acceptable gaps in the mainline traffic, the driver will normally use the first gap. This only becomes critical when the intersection sight distance limits the side-street driver's ability to see if an acceptable gap is available. For this reason it is desirable to have adequate intersection sight distance to allow a driver to recognize when there is an acceptable gap.*

Since intersection sight distance and critical gap time are two different measures, and only slightly compare to each other, the next question to consider is whether the 8.1 and 8.5 seconds used by SRF is an acceptable gap in traffic. Based on a review of critical gap studies and critical gap times used by others (discussed below), the critical gap used by SRF is more conservative than most accepted values, thereby representing a gap that would be acceptable to more than half of the driver population.

Source	2-lane [1]	4-lane [1]
Bissell	6.6s	n/a
AASHTO	7.5s	8.5s
HCM 2000	7.1s	7.5s
Old HCM	8.0s	8.5s
SRF	8.1s	8.5s

(1)Assumes a 55-mph design speed on major road

The gap time used by SRF provides between a 0.5 to 1.0 second buffer over generally accepted values used by AASHTO and the Transportation Research Board. This buffer was developed by assuming an approach volume will consist of 100% trucks (it is unlikely that many intersections will generate 100% truck volumes). Using the figure below from Traffic Flow Fundamentals, a gap of 8.1 seconds would be accepted by over 75% of the driver population. Therefore, SRF's gap times of 8.1 and 8.5 seconds will limit the new intersections to locations where at least 75% of the approaching side street traffic will find an acceptable gap in the mainline traffic during peak hour over the next 20 years.

Other safety factors built into the use of the graphs include:

- It is assumed that 100% of the approaching traffic will be making the left-turn movement (the critical move with the longest critical gap)

- It is assumed that the conflict traffic will correspond to the AADT of the remaining legs of the intersection (it does not reduce the conflicting traffic volume for other turning vehicles at the intersections that will not impact the critical movement).
- The graphs will be based on the estimated 20-year AADT.

- The latest editions of both the AASHTO Green Book and HCM now are using gap time to determine intersection sight distance. This change results in intersection sight distances that are less than the current distances used by Mn/DOT.

The critical gap used in the comparison above is based on the information described below:

A. Highway Capacity Manual 2000

The graphs used by SRF are based on the Highway Capacity Manual 2000 (HCM) and use the information presented in Exhibit 17-5. Based on Exhibit 17-5, the base critical gap acceptance for a left-turn from a minor road is 7.1 seconds for a two-lane road and 7.5 seconds for a four-lane road. The left-turn from a minor movement was used because it has the greatest potential impact on the safety and operations of the roadway. For trucks, the critical gap is increased to 8.1 seconds and 8.5 seconds. When determining the line between high and low risk, SRF used the 100% truck line, thereby establishing the critical gap at 8.1 seconds on two-lane roads and 8.5 seconds on divided roads for all vehicle types.

SRF also included intersections with a very low cross street volume and a very high mainline volume in the high risk area based on the assumption that roadways with a very high mainline volume become unstable and would have a greater chance of adverse impacts from even a small number of vehicles attempting to enter from a cross street.
On page 10-28 of the HCM, it is stated, "In this manual the critical gap and follow up times are considered representative of a statistical average of the driver population in the United States." The statistical average is assumed to be the mean gap time accepted.

B. AASHTO

AASHTO's A Policy on Geometric Design of Highways and Streets 2001 (Green Book), Exhibit 9-54 stated that the critical gap for left-turns from the minor street to a two-lane major road as 7.5 seconds for passenger cars, 9.5 seconds for single unit trucks and 11.5 seconds for semi trucks. On page 663 of the Green Book, it is stated "Field observations of the gaps in major-road traffic actually accepted by drivers turning on to the major road have shown that the values in Exhibit 9-54 provided sufficient time for the minor-road vehicle to accelerate from a stop and complete a left turn without unduly interfering with major-road operations."

The AASHTO Green Book references NCHRP Report 383, Intersection Sight Distance, and states, "Where the time gap acceptance values in Exhibit 9-54 are used to determine the length of the leg of the departure sight triangle, most major-road drivers should not need to reduce speed to less than 70 percent of their initial speed." At 65 mph, the reduction would result in a running speed of 45 mph.

The gap acceptance value is used to derive the Intersection Sight Distance and is expressed in the following equation:

$$d=1.47*V*t$$

d = intersection sight distance (feet)
t = the time gap for minor road vehicles to enter the major road (seconds)

V = speed of vehicles on the mainline (mph)

The equation from the 1990 and 1994 AASHTO Green Books (currently used by Mn/DOT, see below) uses a t = the acceleration time for the minor road vehicle to enter the major roadway.

C. Traffic Flow Fundamentals

In Traffic Flow Fundamentals, by Adolf May, H.H. Bissell, Traffic Gap Acceptance from a Stop Sign, 1960, is referenced. Bissell's research showed a critical gap of 6.6 seconds for left-turns from a minor road. He also developed a graph of gap acceptance (Figure

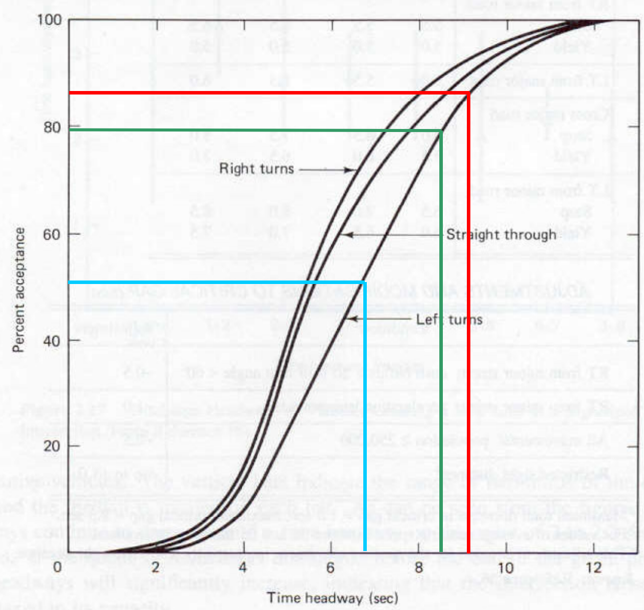


Figure 2.16 Gap Acceptance from a Stop Sign (From Reference 27)

2.16 in May's book). This data may be a bit outdated, but presents a representative picture of driver behavior. Based on this graph:

- The blue line represents 50% of the population will accept a gap of 6.6 seconds
- The red line represents 85% of the population will accept a gap of 9.1 seconds
- The green line represents 80% of the population will accept a gap of 8.5 seconds

Traffic Flow Fundamentals also referenced the old Highway Capacity Manual, Special Report 209. Based on the old HCM, left turns from a stop condition on a minor street is as follows:

- 30 mph (two-lane) 6.5 seconds

- 30 mph (four-lane) 7.0 seconds
- 55 mph (two-lane) 8.0 seconds
- 55 mph (four-lane) 8.5 seconds

Note: If the local population is > 250,000, then the gap acceptance is reduced by –0.5 seconds.

The old HCM used data from a limited number of studies to develop these critical gap times.

D. <u>Mn/DOT Road Design Manual</u>

The Mn/DOT Road Design Manual does not directly address gap acceptance in its policy on intersection sight distance (ISD). The guidance in the Mn/DOT Road Design Manual is based of the 1990 and 1994 AASHTO Green Book.

The Intersection Sight Distance shown in Figure 5-2.02G is based on the equation:

$$d = 1.47V(J+t)$$

d = intersection sight distance (feet)

J = the perception/reaction time (2.0 seconds),

t = the time required for a vehicle to accelerate, traverse the intersection and merge into the mainline based on Figure 5-2.02D. (seconds)

V = the design speed of the major roadway (mph)

This equation is based on the acceleration rate of the turning vehicle and assumed that the turning vehicle would not impact the speed of traffic on the major road.

Using Figure 5-2.02G and solving for t:

- At 30 mph, t would be 7.1 seconds.
- At 45 mph, t would be 10.1 seconds.
- At 55 mph, t would be 12.8 seconds.
- At 60 mph, t would be 14.8 seconds.

This time (t) represents the length of time required for a vehicle to accelerate from a stopped position to the average running speed of the major roadway. Therefore, the time required accelerating increases as the design speed for the major roadway increases. This time is representative of the operating characteristics of the vehicle and not the actions of the driver. In the 2001 AASHTO Green Book, this approach has been changed to one that uses gap acceptance, as discussed above.

E. End Notes

When compared to the acceptable critical gap times used by AASHTO and TRB in the HCM, the SRF critical gap times represent a conservative approach that will provide guidance to the spacing of conditional intersections. Additional factors will also be used and tend to be more restrictive when looking at secondary intersection locations.

To validate whether the critical gap is a factor on the crash rate of an intersection, further investigation could look at intersections with known crash rates, and known traffic volumes and plotted on the graphs developed by SRF to see if there is a concentration of high crash rate locations near the line separating high and low risks.