Left-Turn Lane Installation Guidelines

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ABSTRACT

The addition of a left-turn lane can improve the operations and safety at an intersection. Guidelines as to when to include a left-turn lane in intersection design are plentiful. Because of the quantity of methods, questions are asked regarding which method to use. This paper reviewed eight selected techniques and a number of criteria present in state manuals. Methods based on delay typically do not recommend a left-turn lane at lower left or through volumes when compared to methods based on conflict avoidance or safety. Because of the high benefits for crash reductions provided by left-turn lanes, a method that results in a recommendation at lower volumes would be preferred. The Harmelink model is a widely accepted approach that is based on conflict avoidance. The procedure was first proposed in 1967 and includes assumptions that may need to be revised. Findings from current research would suggest a critical gap of 5.5 sec (rather than 5.0 sec), a time to make left turn of 4.3 sec (rather than 3.0 sec), and a time to clear the lane of 3.2 sec (rather than 1.9 sec). A table was developed that lists suggested guidelines for installing left-turn lanes for operating speeds of 30, 50, and 70 mph (50, 80, and 110 km/h).

BACKGROUND

The addition of a left-turn lane can improve the operations and safety at an intersection. A recent FHWA study found that the addition of a left-turn lane can result in reductions of crashes from 7 to 48 percent.[1] Other studies have demonstrated the benefits of delay reductions with the installation of a left-turn lane on two-lane highways.[2] Guidelines as to when to include a left-turn lane in intersection design are plentiful. Some are based on minimizing conflicts in terms of the occurrence of a through vehicle arriving behind a turning vehicle; others are based on decreasing the amount of delay to through vehicles, and some are based on consideration of safety. Because of the quantity of methods, questions are asked regarding which method to use. For example, are certain techniques better for a rural versus an urban setting? Do the evaluations differ for number of lanes and for type of intersection? This paper reviewed eight selected techniques and a number of criteria present in state manuals. Some of the assumptions used in the techniques will be reviewed, and suggestions on changes to selected guidelines will be made.

Common terms are used in several of the techniques. Figure 1 graphically shows the following movements that are used to determine the need for a left-turn lane in several of the guidelines:

- Advancing Volume (V_A) – the total peak hourly volume of traffic on the major road approaching the intersection from the same direction as the left-turn movement under consideration.
- Left-Turn Volume (V_L) – the portion of the advancing volume that turn left at the intersection.
- Percent Left Turns (P_L) – the percentage of the advancing volume that turn left; equal to the left-turn volume divided by the advancing volume ($P_L = V_L \div V_A$).
- Straight Through Volume (V_S) – the portion of the advancing volume that travel straight through the intersection ($V_L + V_S = V_A$).
- Opposing Volume (V_O) – the total peak hourly volume of vehicles opposing the advancing volume.

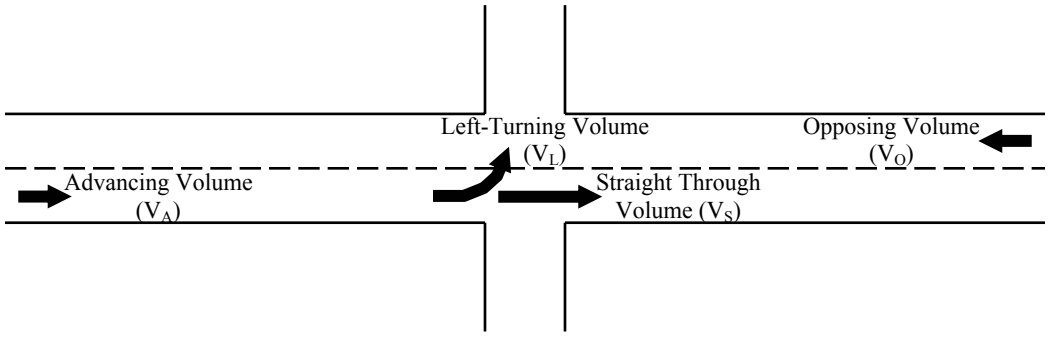


Figure 1. Volumes for Use in Left-Turn Lane Warrant Methods.

GUIDELINES REVIEWED

A review of the literature was performed on many sources, including research reports, state and federal design manuals, and handbooks. Although many techniques are currently in use by various organizations to determine the need for left-turn lanes, several are either very similar or identical. Details are provided below on those methods that appeared to have distinctive results.

Harmelink

The oldest research found on evaluating the need for left-turn lanes at unsignalized intersections was that of M.D. Harmelink[3] in a paper that was published in 1967. His research provided the foundation for many current left-turn guidelines. Harmelink based his work on a queuing model in which arrival and service rates are assumed to follow negative exponential distributions. He states that the probability of a through vehicle arriving behind a stopped, left-turning vehicle should not exceed 0.02 for 40 mph (64 km/h), 0.015 for 50 mph (80 km/h), and 0.01 for 60 mph (96 km/h). He presented his criteria in the form of graphs, 18 in all. To use his graphs, the advancing volume, opposing volume, operating speed, and left-turn percentage need to be known. Graphs for speeds of 40, 50, and 60 mph (64, 80, and 96 km/h) were given, as well as 5, 10, 15, 20, 30, and 40 percent left-turn volumes. An example graph of Harmelink's criteria for determining the need for left-turn lanes is shown in Figure 2.

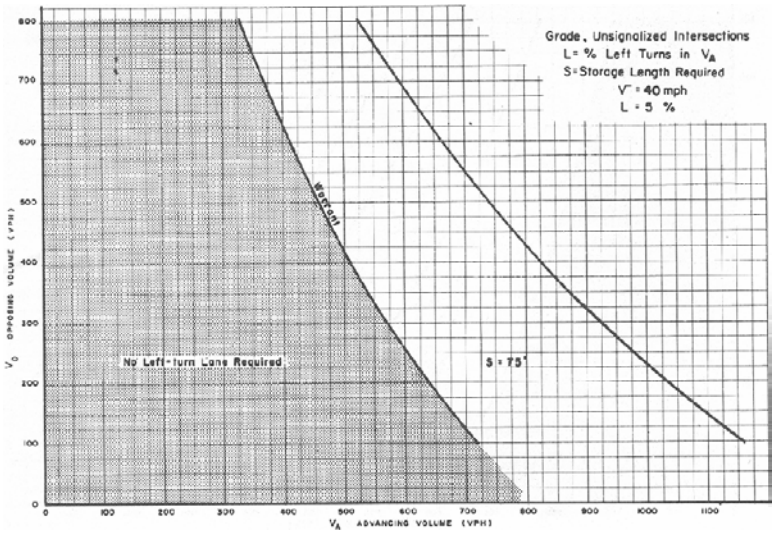


Figure 2. Harmelink – Left-Turn Lane Warrant Graph, 40 mph (64 km/h), 5% Left Turns, 1967.[3]

AASHTO Green Book

AASHTO's *Green Book*[4] contains a table for use in determining the need for a left-turn lane on two-lane highways (see Table 1). Similar tables were also present in the 1984,[5] 1990,[6] and 1994[7] editions of the *Green Book*. The values in the table are based upon Harmelink's work.

Table 1. AASHTO – Guide for Left-Turn Lanes on Two-Lane Highways, 2001.[4]

Opposing Volume (vph)	Advancing Volume (vph)			
	5% Left Turns	10% Left Turns	20% Left Turns	30% Left Turns
40 mph (60 km/h) operating speed				
800	330	240	180	160
600	410	305	225	200
400	510	380	275	245
200	640	470	350	305
100	720	515	390	340
50 mph (80 km/h) operating speed				
800	280	210	165	135
600	350	260	195	170
400	430	320	240	210
200	550	400	300	270
100	615	445	335	295
60 mph (100 km/h) operating speed				
800	230	170	125	115
600	290	210	160	140
400	365	270	200	175
200	450	330	250	215
100	505	370	275	240

NCHRP Report 279

In 1985, the Transportation Research Board published NCHRP Report 279, *Intersection Channelization Design Guide*.[8] In that report, data from Harmelink's work were used to establish guidelines for determining the need for a left-turn lane. The following advice was provided for unsignalized intersections:

1. Left-turn lanes should be considered at all median cross-overs on divided, high-speed highways.
2. Left-turn lanes should be provided at all unstopped (i.e., through) approaches of primary, high-speed rural highway intersections with other arterials or collectors.
3. Left-turn lanes are recommended at approaches to intersection for which the combination of through, left, and opposing volumes exceeds the warrants shown in Figure 3.
4. Left-turn lanes on stopped or secondary approaches should be provided based on analysis of the capacity and operations of the unsignalized intersection. Considerations include minimizing delays to right turning or through vehicles and total approach capacity.

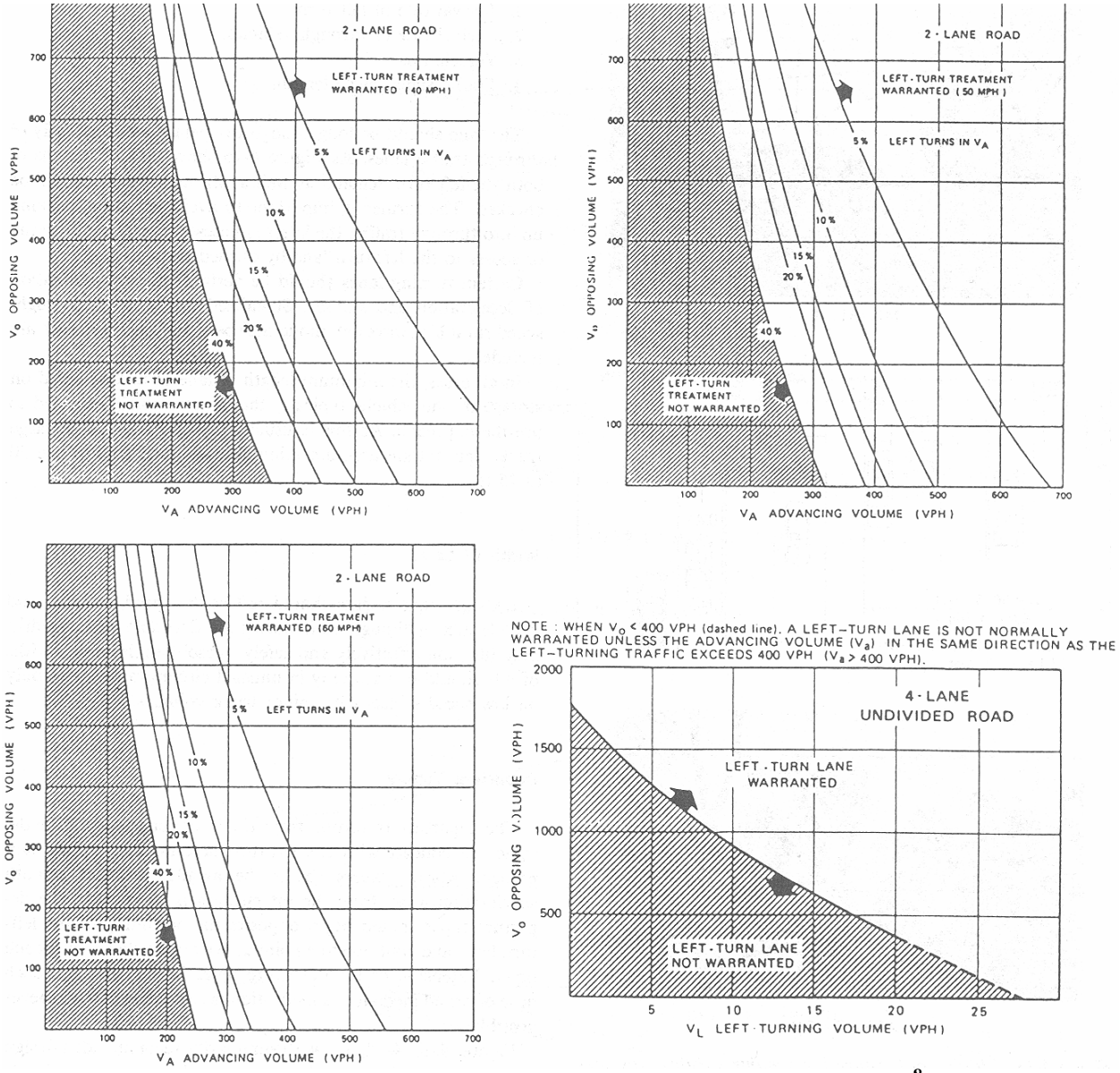


Figure 3. NCHRP 279 – Left-Turn Lane Guidelines, 1985.[8]

Oppenlander and Bianchi (ITE Technical Committee)

ITE Technical Committee 4A-22 in the 1980s undertook the task of developing criteria for the provision of separate left-turn lanes at unsignalized and signalized intersections.[9] The work performed by ITE Committee 4A-22 expanded the Harmelink model to include additional speeds (30- and 70-mph [48 and 113 km/h] roadways) and to include additional left turn percentages. An example of one of the guideline graphs produced is shown in Figure 4.

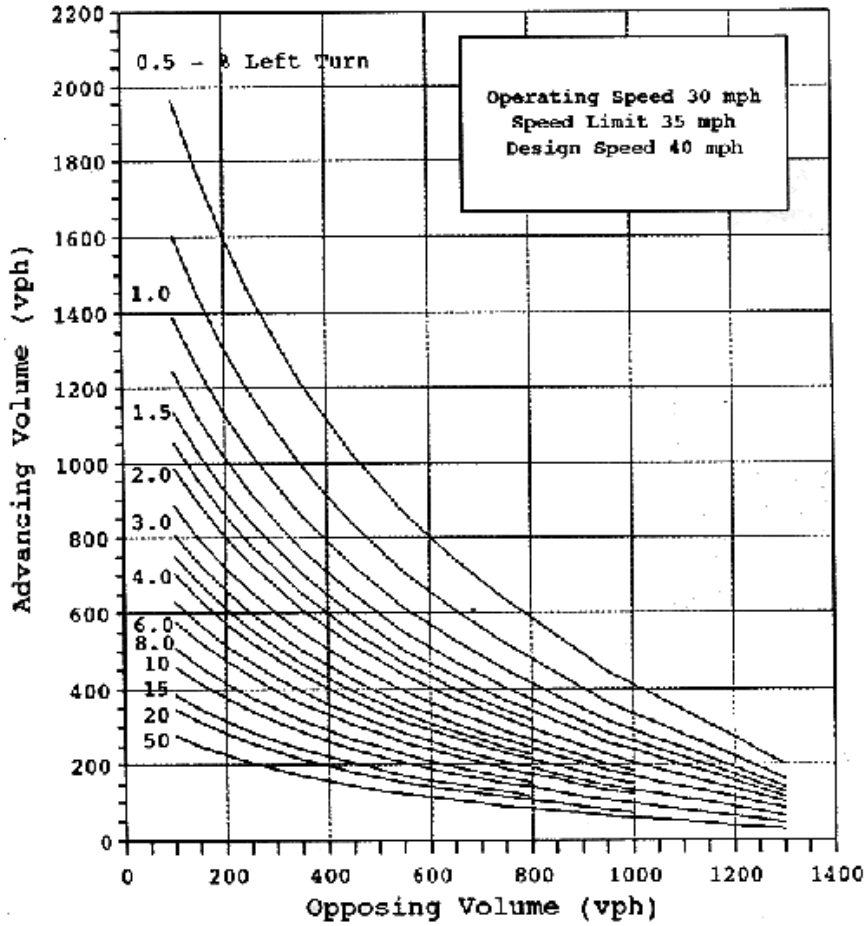


Figure 4. Oppenlander and Bianchi – Left-Turn Lane Guidelines; Unsignalized, Two-Lane, 30 mph (48 km/h) Operating Speed, 1990.[9]

NCHRP Report 348

F. J. Koepke and H. S. Levinson provided two methods for determining the need for left-turn lanes in NCHRP Report 348.[10] The first method is shown in Figures 5 and 6; however, Koepke and Levinson state that in most cases, left-turn lanes should be provided where there are more than 12 left turns per peak hour. The second method presents the values included in the *Green Book* for determining whether a left-turn lane should be provided. They also stated that "left-turn lanes should be provided when delay caused by left-turning vehicles blocking through vehicles would become a problem." They emphasize the fact that separate left-turn lanes not only increase intersection capacity, but also increase vehicle safety.

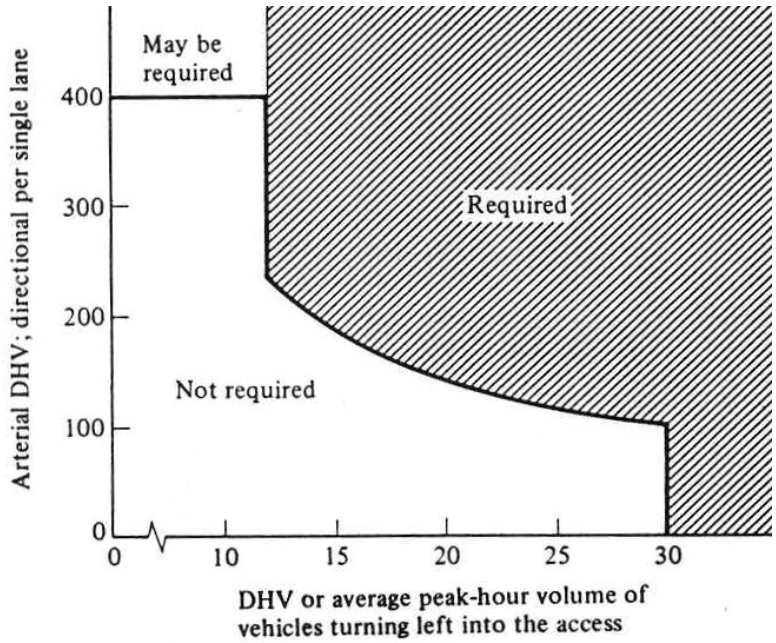


Figure 5. NCHRP Report 348 – Left-Turn Lane Guidelines for 30-35 mph (48-56 km/h), 1992.[10]

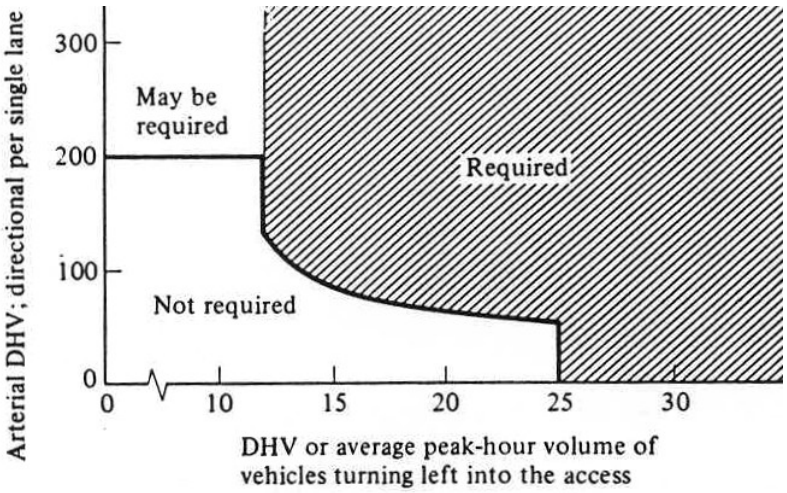


Figure 6. NCHRP Report 348 – Left-Turn Lane Guidelines for 40-45 mph (64-72 km/h), 1992.[10]

Modur et al.

A Texas study by Modur et al. examined the choice of median design and developed a set of guidelines for determining when to recommend left-turn lanes for arterial streets with speeds less than 45 mph (72 km/h).[11] The guidelines were developed using delay data generated from a simulation model. Table 2 shows the developed guidelines. The authors noted that sections with left-turn treatments are better than the sections with no treatments, and they recommended that left-turn treatments be used in sections with a disproportionately large number of crashes even though not warranted due to the operational criteria.

Table 2. Modur et al. – Left-Turn Lane Warrant Chart, 1990.[11]

Opposing Traffic Volume per Lane per Hour	400-600				<200	Hourly Left-Turn Traffic Volume
	200-400					
	0-200					
	400-600				200-400	
	200-400					
	0-200					
	400-600				400-600	
	200-400					
	0-200					
		0-150	150-300	300-450		
Hourly Straight Through Traffic Volume per Lane						

Black boxes denote that a left-turn treatment is desirable, provided it can be accommodated within the available right-of-way and pavement width. Gray boxes mean that an operational left-turn treatment may be considered. Left-turn lane or raised median is satisfactory based on individual site considerations. White boxes signify that no left-turn treatment is required based on operational considerations.

Hawley and Stover

Hawley and Stover also used delay to generate guidelines on when to install a left-turn lane on four-lane undivided arterials.[12] They considered the delay to though vehicles and asked under what volumes turning vehicles would seriously impact through traffic. They then evaluated the proposed guidelines with a conflict analysis that was based on the probability of two vehicles arriving at the intersection at the same time to assess the safety aspects of the guidelines. A probability of 0.01 was selected as the maximum likelihood of a conflict. The philosophy of the new guidelines focuses on recommending a left-turn lane above a set directional volume rather than a set turn volume. Figure 7 is a graph of the curves recommended.

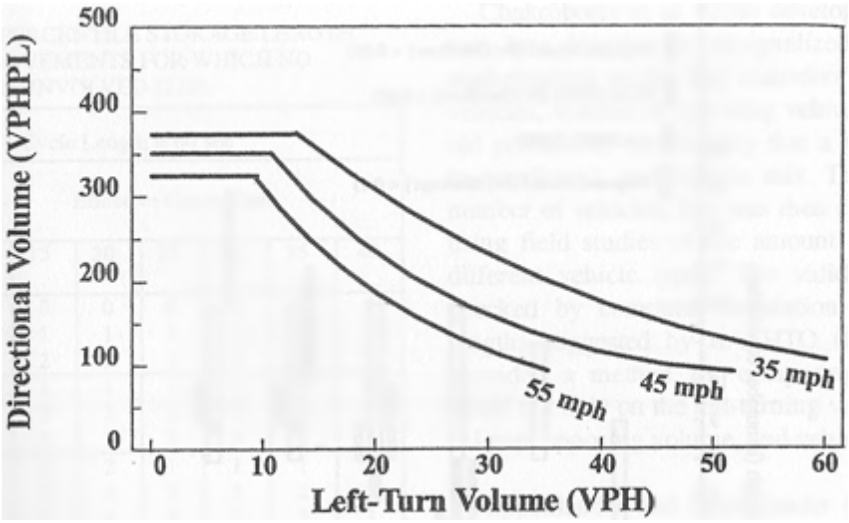


Figure 7. Hawley and Stover – Left-Turn Lane Guidelines for Four-Lane Undivided Arterial Street with Nonplatoon Flow, 1996.[12]

NCHRP Report 457

In 2001, Bonneson and Fontaine[13] in NCHRP Report 457 discussed the determination of when to consider a left-turn lane. They sited work by Neuman[8] (which was based on the Harmelink model) and recreated the Harmelink model as an interactive spreadsheet (available on the Internet as Figure 2-5 in the NCHRP report at: http://trb.org/trb/publications/nchrp/esg.pdf).

State Manuals

Several state manuals also include information on when to consider a left-turn lane. The Texas Department of Transportation *Roadway Design Manual*[14] contains the same table of criteria as the values included in the *Green Book*[4] for determining the need for a left-turn lane. The Mississippi Department of Transportation's *Roadway Design Manual*[15] recommendations for the inclusion of left-turn lanes uses graphs similar to those presented in NCHRP Report 279 (which is based on Harmelink's work).

Chapter 5 of the New York State Department of Transportation's *Highway Design Manual*[16] refers readers to the AASHTO *Green Book* for traffic volume criteria to be considered in determining the need for left-turn lanes. It also includes discussion on the potential to reduce crashes with the installation of a left-turn lane and states that sight distance on the major road is another factor that can create a need for an exclusive left-turn lane.

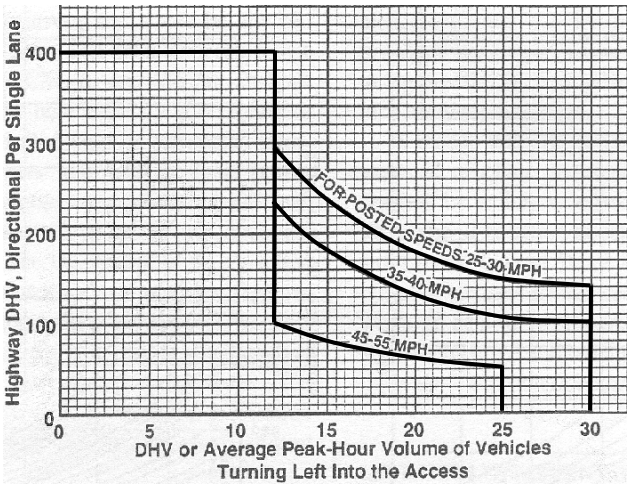
In the *Project Development Manual*,[17] the Missouri Department of Transportation (MoDOT) considers left-turn lanes to be necessary where the number of left-turning vehicles is 100 vph or more during the peak hour. Two-lane left turns are considered when volumes exceed 300 vph. MoDOT also states that the AASHTO *Green Book* should be used as a guide and that left-turn lanes should be considered at intersections where traffic volumes do not warrant but poor visibility or crash records indicate a need.

In its *Location and Design Manual*,[18] the Ohio Department of Transportation recommends that left-turn lanes be installed when left-turn design volumes:

- Exceed 20 percent of total directional approach design volumes, or
- Exceed 100 vehicles per hour in peak periods.

In Utah, left-turn movements are the only deciding factors for determining the need for an exclusive left-turn lane in rural areas. The *Roadway Design Manual of Instruction*[19] states that in rural areas where there are 25 or more left-turn movements for the main highway in the peak hour, left-turn lanes should be considered. The need for left-turn lanes at signalized intersections is determined by capacity analysis and the acceptable level of service designated for the facility.

The Idaho Transportation Department (ITD) performed a study on left-turn lanes in regards to speed, volume, sight distance, passing opportunity, number of anticipated turning movements, and crash history.[20] From that study, ITD determined that the need for left-turn lanes should be established by considering the advancing volume, left-turn volume, and the operating speed, as shown in Figure 8.



(1 mi = 1.61 km/h)

Figure 8. Idaho Transportation Department – Left-Turn Lane Warrant Graph, 1994.[20]

COMPARISON OF METHODS

Several methods use the Harmelink model as the basis of their guidelines, such as the guidelines present in the AASHTO *Green Book* and in several NCHRP reports. These guidelines require the knowledge of volumes on each major approach along with the left-turning volume or percentage.

Some of the guidelines, especially a sample of those in state manuals, are based on design hour volumes. The use of design hour volume or left-turn design hour volume lends itself to easier use in a planning stage since volumes on individual major road approaches are not required. The identified procedures can also be subdivided by number of lanes and by speed (which could imply an urban and rural categorization).

Tables 3 and 4 summarize selected techniques from the literature and state manuals, respectively. Figures 9 and 10 show a comparison of the methods for a 40-mph (64 km/h) operating speed and a 55-mph (89 km/h) operating speed, respectively, for a two-lane roadway with 10 percent left turns. Figure 11 shows a comparison of the methods for four-lane roadways.

When the various methods are compared (as shown in Figures 9 and 10), the methods presented in the AASHTO *Green Book* and the NCHRP Reports 279 and 457 overlap, as expected. Not expected was the difference between the AASHTO methods and the numbers provided by Oppenlander and Bianchi. These lines should also have overlapped since they were based on the same methodology. The reason for the difference is not apparent. Other methods available for two-lane highways that use similar criteria as AASHTO would recommend left-turn lanes at lower volumes (see the curve for IDT on Figure 10 as an example). The different methods available for four-lane highways show greater diversity for when a left-turn lane would be recommended (see Figure 11).

Table 3. Summary of Selected Left-Turn Lane Literature Guidelines.

Method	AASHTO (2001,[4] 1994,[7] 1990,[6] 1984[5])	NCHRP 279 (1985),[8] NCHRP 457 (2001)[13]	Oppenlander and Bianchi (1990)[9]	Modur et al. (1990)[11]	NCHRP 348 (1992)[10]	Hawley and Stover (1996)[12]
Roadway Type	Two-lane	Two-way stop controlled	Two-lane unsignalized	Urban (roadways less than 45 mph [70 km/h])	Any unsignalized	Four-lane undivided
Developed with consideration of:	Minimize conflict	Minimize conflict	Minimize conflict and safety	Delay	Not specified	Delay
Key Feature	Based on Harmelink's 1967 study. Developed table of values for various speeds and left turn percentages.	Based on Harmelink's 1967 study. NCHRP 457 includes a spreadsheet to perform calculations.	Used Harmelink's model and expanded to additional speed ranges. Also added consideration of crashes.	Used simulation to determine guidelines.	Would recommend for lower left-turn volumes than other methods.	Used results from simulation to determine value.
Crashes	"…safety considerations are sufficient to warrant them."	States that there are benefits in crash reduction when left-turn lane is added.	Crashes by approach that would involve a left-turning vehicle: 4 per year at unsignalized and 5 per year at signalized.	"Sections with left-turn treatments are always better than the sections with no treatment."	"Separate turning lane…promote the safety of all traffic."	Guidelines checked against maximum probability of conflict of 0.01. Recommends that the designer consider potential crashes.

Table 4. Summary of State Methods.

State	Primary Method	Also Include Consideration of
Texas	*Green Book*	
Mississippi	Harmelink	Crashes and sight distance
New York	*Green Book*	Crashes and sight distance
Missouri	Left turn exceeds 100 vph *Green Book*	Crashes and sight distance
Ohio	Left turn exceeds 100 vph in peak period or 20% of total directional approach design volumes	
Utah	Left turn exceeds 25 vph	
Idaho	Unique graphs, in many cases 12 to 25 design hour volume of left turns	Crashes (4 per year on an existing approach)

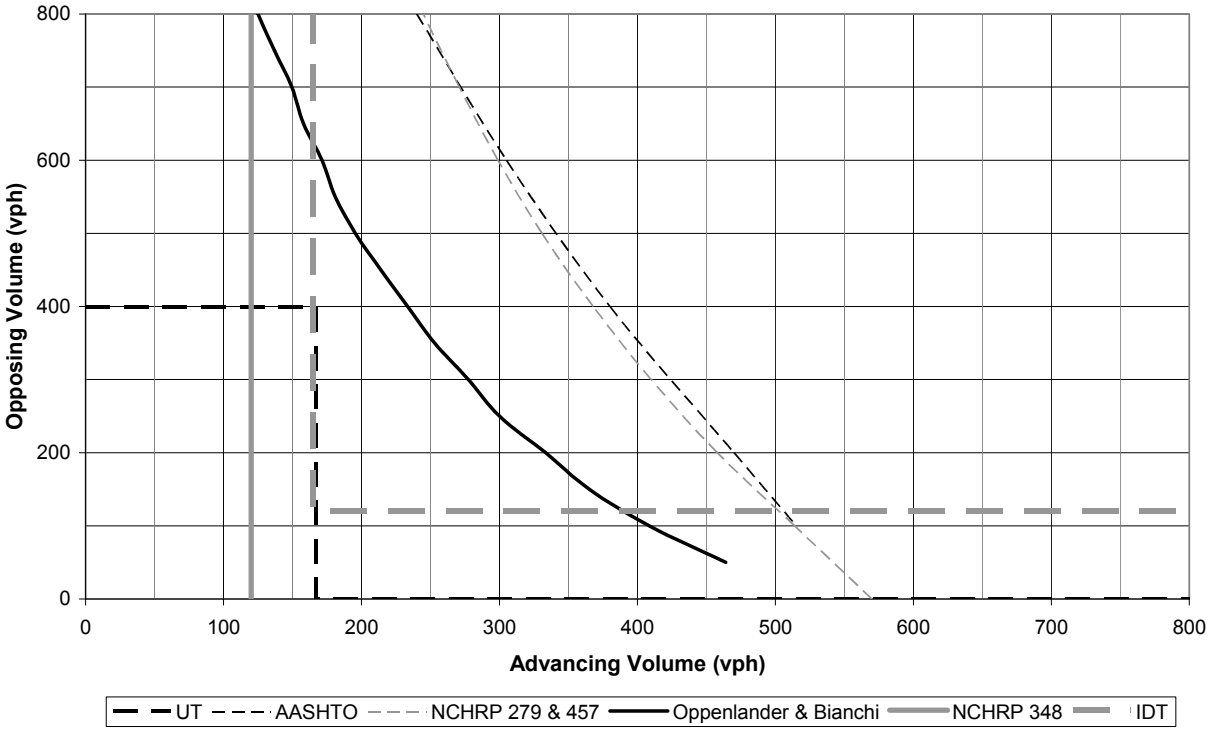


Figure 9. Comparison of Left-Turn Lane Installation Guidelines for 10% Left Turns, 40 mph (64 km/h), Two-Lane Highways.

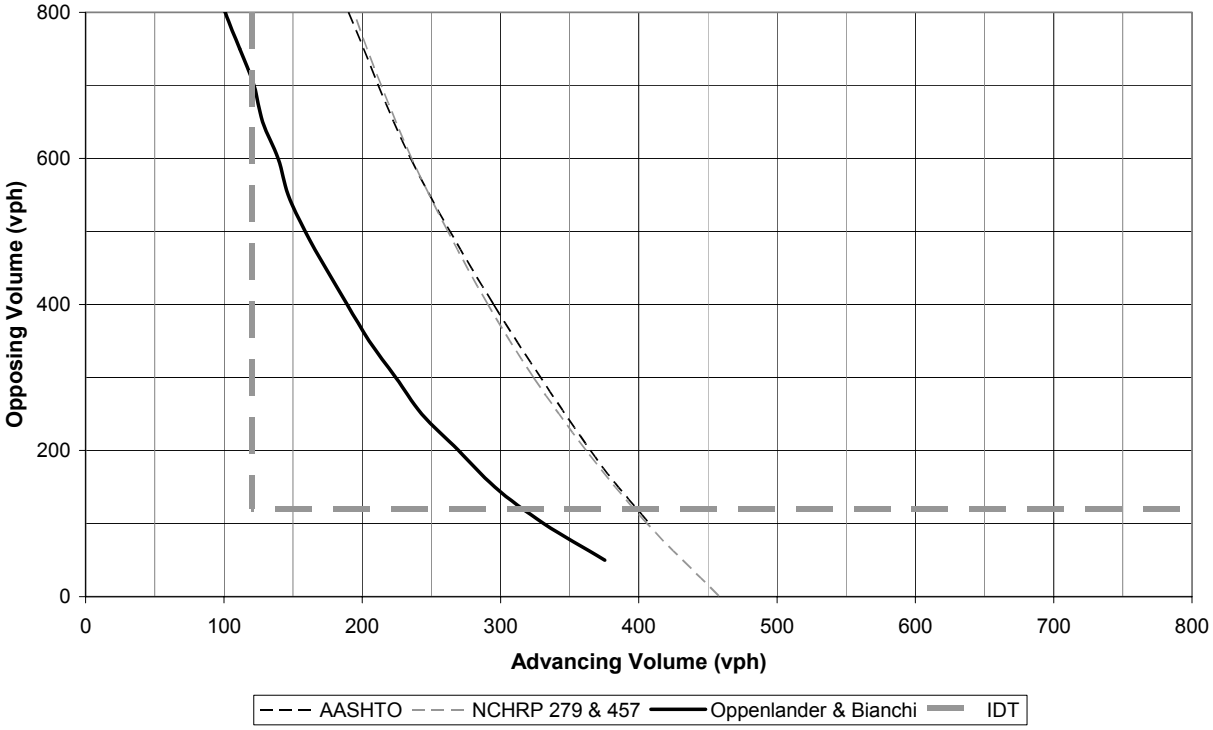


Figure 10. Comparison of Left-Turn Lane Installation Guidelines for 10% Left Turns, 55 mph (89 km/h), Two-Lane Highways.

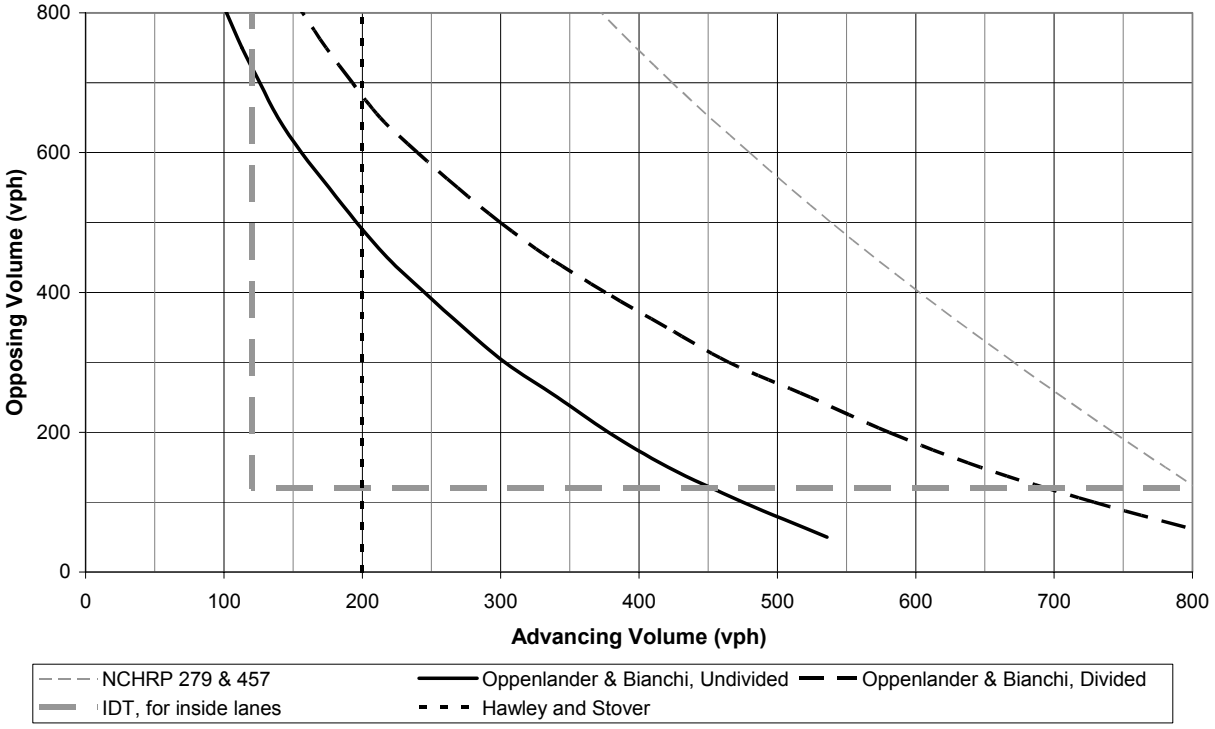


Figure 11. Comparison of Left-Turn Lane Installation Guidelines for 10% Left Turns, 55 mph (89 km/h), Four-Lane Highways.

Several state methods only use a left-turn requirement; hence those methods are not shown in Figures 9 and 10 because advancing or opposing volume requirements are not included. They are shown in Figures 12 and 13 with left-turn volume being on the y axis for 40 and 55 mph (64 and 89 km/h), respectively. The left-turn lane should be considered when the volume plots above or to the right of a curve. In most cases, the methods that use only left-turn volumes recommend a left-turn lane at lower volumes than the method present in the AASHTO *Green Book*.

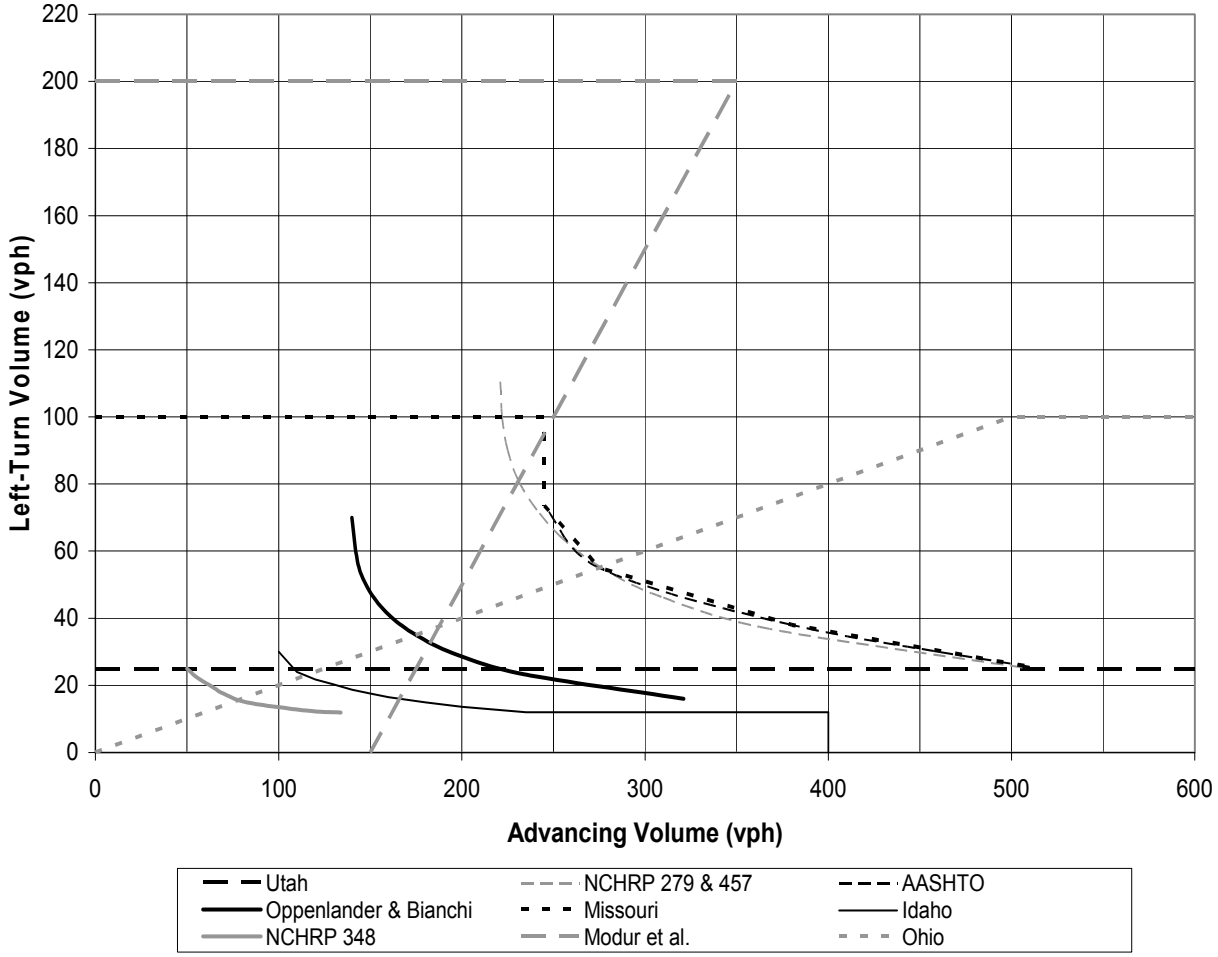


Figure 12. Comparison of Left-Turn Lane Installation Guidelines for Opposing Volume of 400 vph, 40 mph (64 km/h), Two-Lane Highways.

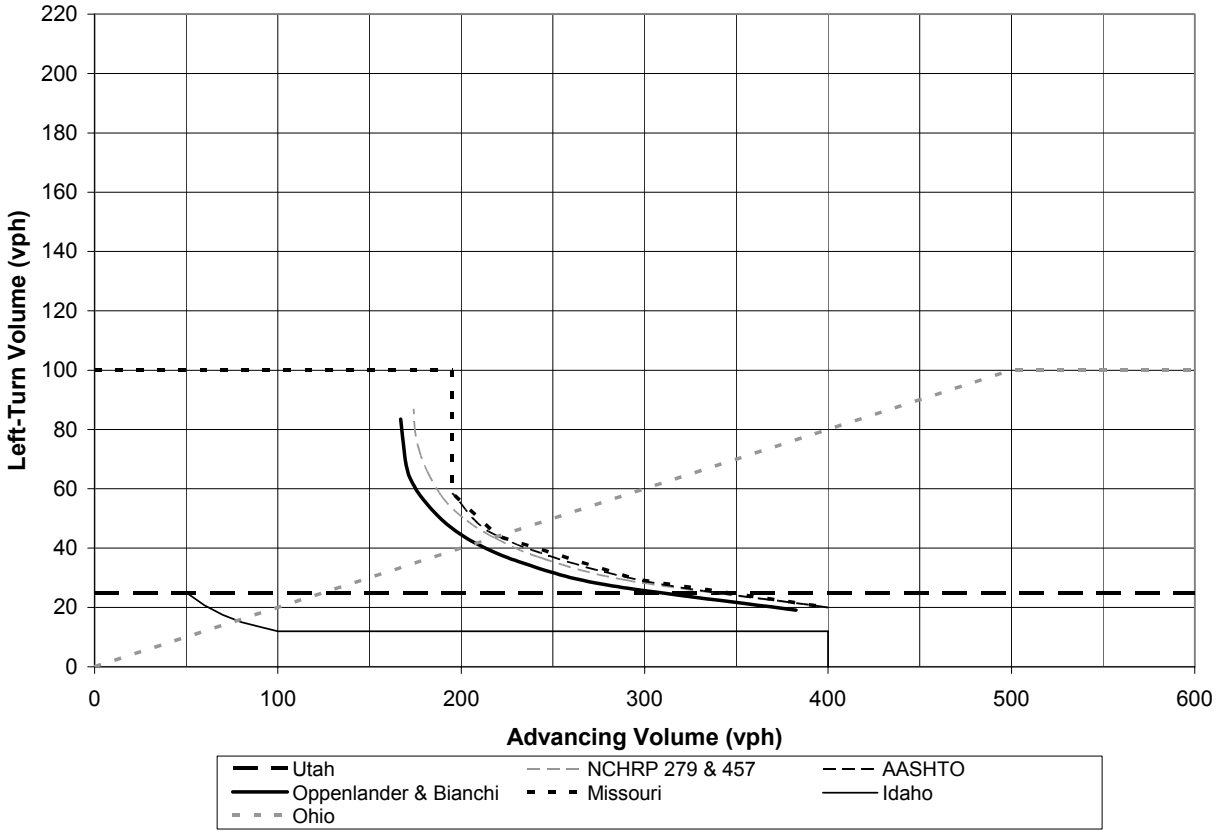


Figure 13. Comparison of Left-Turn Lane Installation Guidelines for Opposing Volume of 400 vph, 55 mph (89 km/h), Two-Lane Highways.

UPDATING OF ASSUMPTIONS

In many design manuals, a procedure based on the Harmelink model is the accepted approach. The guidelines developed by Harmelink include the following assumptions:

- Probability of a through vehicle arriving behind a stopped left-turning vehicle should not exceed 0.02 for 40 mph (64 km/h), 0.015 for 50 mph (80 km/h), and 0.010 for 60 mph (96 km/h).
- Arrival-time and service-time distributions are negative exponential.
- Average time required for making a left turn is 3.0 sec for two-lane highways and 4.0 sec for four-lane highways as determined from field studies.
- Critical headway in the opposing traffic stream for a left-turn maneuver is 5.0 sec on two-lane highways and 6.0 sec on four-lane highway as determined from field studies.
- Average time required for a left-turning vehicle to clear or "exit" from the advancing lane is 1.9 sec as determined from field studies.

Probability of Through Vehicle Arrival

Harmelink's assumption for avoiding the arrival of a vehicle behind a left-turning vehicle was scaled to the speed of the facility. He had a lower probability for the higher speed roadways. This assumption should be reflected in calculations for other operating speeds, such as using 0.025 for 30 mph (48 km/h) and 0.005 for 70 mph (113 km/h).

Critical Headway

Several recent research projects have determined the critical gap for use in intersection sight distance calculations and unsignalized intersection capacity analysis. As reported by Harwood et al.,[21] Kyte et al. recommended a critical gap value of 4.2 sec for left turns from the major road by passenger cars for inclusion in the unsignalized intersection analysis procedures of the *Highway Capacity Manual.*[22] A heavy-vehicle adjustment of 1.0 sec for two-lane highways and 2.0 sec for multilane highways was also recommended.

A study in Pennsylvania by Miscky and Mason recorded critical gap data for two intersections. They used logistic regression and found critical gaps for a 50 percent probability of acceptance of 4.6 and 5.3 sec.[23] They also found 85th percentile gaps of 5.5 and 5.9 sec at the two intersections.

It is reasonable that design policies should be more conservative than operational criteria such as the *Highway Capacity Manual.* Using a higher critical gap value, such as the value accepted by 85 percent of the drivers rather than the gap accepted by only 50 percent of the drivers, would result in a more conservative, design-oriented approach. With that philosophy the authors of the 1996 intersection sight distance guidelines recommended a 5.5 sec gap value for use in intersection sight distance.[21] This gap value should be increased to 6.5 sec for single-unit trucks, 7.5 sec for combination trucks, and an additional 0.5 sec for cars and 0.7 sec for trucks should be added when crossing an additional opposing lane.

Harmelink's assumption of 5.0 sec for the critical gap value is near to the values identified in more recent research. If a more conservative gap value for use in design is desired, then the critical gap value should be increased to 5.5 or 6.0 sec. If heavy trucks are a concern at the site, then a higher critical gap should be considered, generally on the order of 0.5 to 1.0 sec increase in the value assumed for passenger cars.

Time to Make a Left Turn

The 1994 AASHTO *Green Book*[7] included information on the amount of time to accelerate and clear an intersection. Assuming minimum travel path and crossing one lane, Miscky and Mason calculated that a left-turning vehicle would travel approximately 47 ft (14.3 m) to clear the opposing lane. Using Figure IX-33 in the 1994 *Green Book*, the estimated time is 4.3 sec for a passenger car accelerating from a stop (which would be the more critical situation). Miscky and Mason also found the travel time for left-turning vehicles at two intersections in Pennsylvania. The mean values were 4.0 and 4.3 sec while the 85th percentile values were 4.6 and 5.1 sec at the

two intersections. The authors noted that the longer turning time at the one intersection was caused by vehicles starting farther back than what is assumed in the theoretical model.

Vehicles turning left were recorded at a rural T-intersection in Texas. The major roadway had 11-ft (3.4 m) lanes and no shoulders with a 55 mph (89 km/h) speed limit. The data were collected between 7 to 9 am or 2 to 4 pm on two consecutive days. A total of 307 vehicles were recorded making left turns during the 8-hour period with 71 beginning the turn from a stopped position. The times when a left-turning vehicle began the turn, completely cleared the advancing lane, and completely cleared the opposing lane were recorded. For the vehicles beginning the turn from a stopped position, 85 percent cleared the intersection in 4.1 seconds (see Figure 14).

In his field studies, Harmelink found that only 3.0 sec was needed to make the left-turn. Using the 1994 AASHTO *Green Book* results in a value of 4.3 sec, recent research at two Pennsylvania intersections found 5.1 sec (85th percentile value) for the time to cross the opposing lane, and data from a Texas intersection found 4.1 sec. While the more recent research was performed at only three locations, it appears that Harmelink's assumption of 3.0 sec is low.

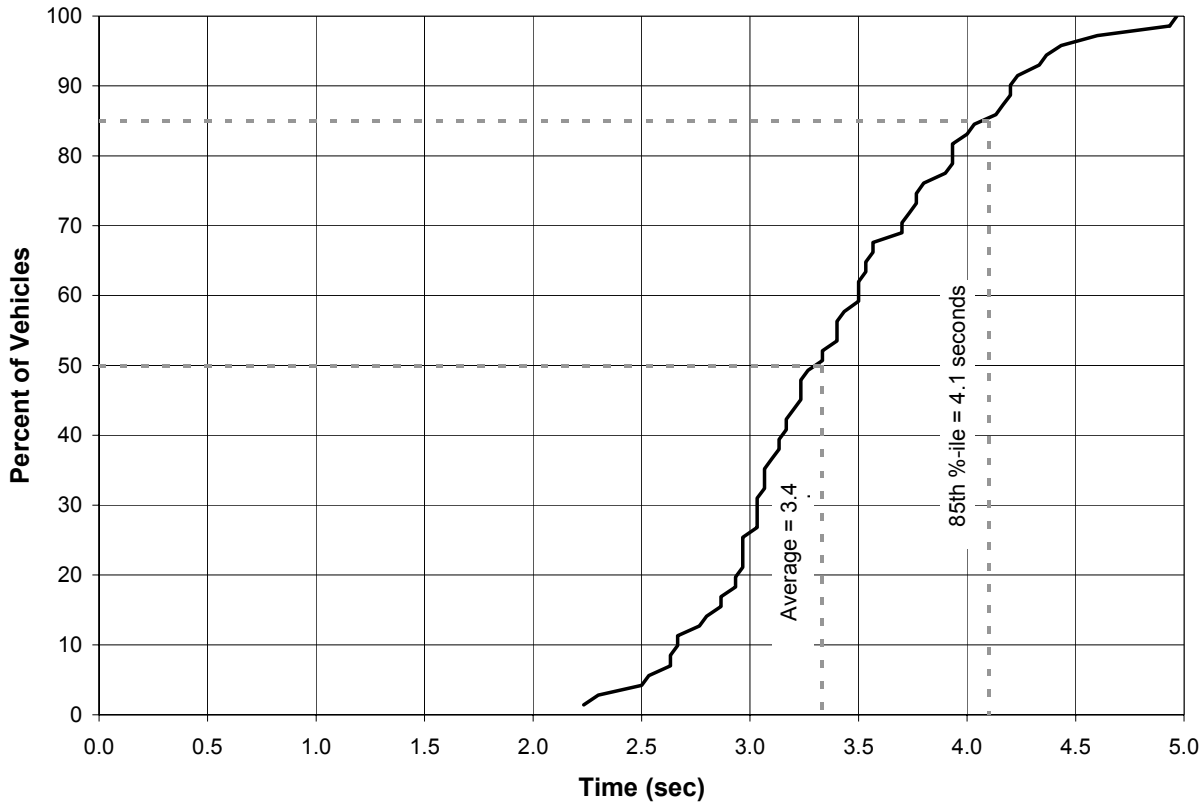


Figure 14. Percentile Values for Time to Clear the Opposing Lane When Making a Left Turn.

Time Required to Clear

Data on the amount of time to clear the advancing lane that is more recent than the value reported by Harmelink were not found except for the data available from the one rural Texas T-intersection discussed above. For the vehicles beginning the turn from a stopped position, 85 percent used 3.2 seconds to clear the lane as shown in Figure 15.

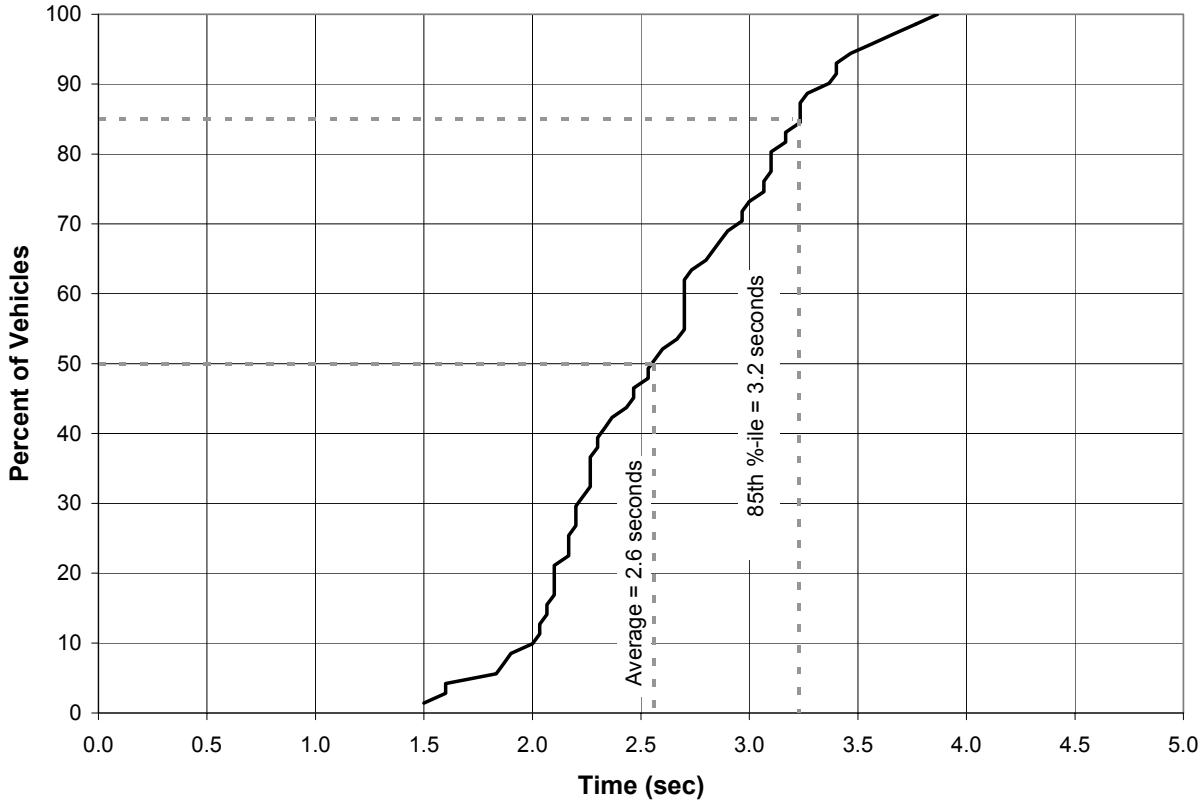


Figure 15. Percentile Values for Time to Clear the Advancing Lane When Making a Left Turn.

Comparison Using New Assumptions

Using more recent findings, suggested assumptions for use in the Harmelink model are:

- Critical headway for a left-turn maneuver is 5.5 sec.
- Time to complete the left turn and clear the opposing lane is 4.3 sec.
- Time to clear the advancing lane is 3.2 sec.

Figure 16 illustrates the change in the curves when the above assumptions are used.

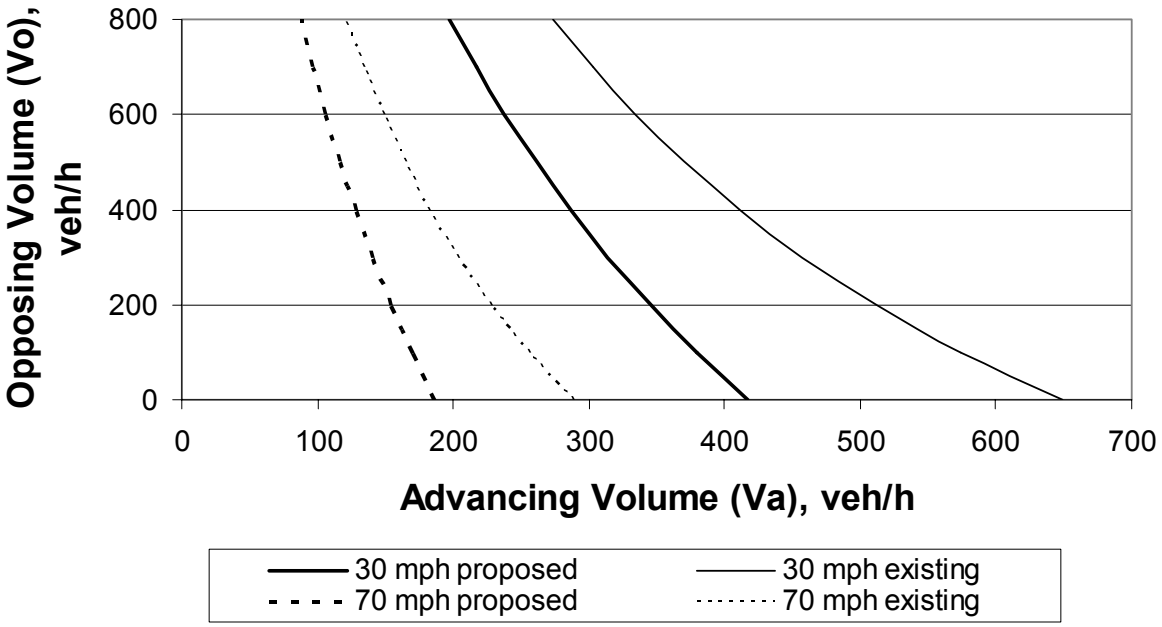


Figure 16. Comparison of Existing to Proposed Guidelines (Example Uses 10% Left Turns).

CONCLUSIONS

Several methods are available for determining when to include a left turn lane in the design at an intersection. Methods based on delay typically do not recommend a left-turn lane at lower left or through volumes when compared to methods based on conflict avoidance or safety. Because of the high benefits for crash reductions provided by left-turn lanes, a method that results in a recommendation at lower volumes would be preferred. The Harmelink model is a widely accepted approach that is based on conflict avoidance. The procedure first proposed by Harmelink in 1967 includes assumptions that may need to be revised. Findings from current research on the time to clear an intersection and on critical gaps suggest that Harmelink guidelines should be modified. Table 5 lists suggested guidelines for installing left-turn lanes for operating speeds of 30, 50, and 70 mph (50, 80, and 110 km/h).

If the Harmelink approach is preferred and the operating speed of interest (or number of lanes) is not provided in Table 5, the reader can use the interactive spreadsheet included as part of NCHRP 457 (http://trb.org/trb/publications/nchrp/esg.pdf). The assumptions need to be changed to match those at the intersection of interest or to reflect more recent research findings such as using a critical gap of 5.5 sec, a time to make left turn of 4.3 sec, and a time to clear of 3.2 sec.

Table 5. Guidelines for Installing Left-Turn Lanes on Two-Lane Highways.

Vo	Percent Left Turns		
	10	20	40
30 mph (50 km/h)			
800	197	148	121
700	217	162	133
600	238	178	146
500	261	196	160
400	286	215	175
300	314	236	193
200	345	259	211
100	380	285	232
0	418	313	256
50 mph (80 km/h)			
800	153	115	94
700	168	126	103
600	184	138	113
500	202	152	124
400	222	166	136
300	244	183	149
200	268	201	164
100	294	221	180
0	323	243	198
70 mph (110 km/h)			
800	88	66	54
700	97	73	59
600	106	80	65
500	117	88	71
400	128	96	78
300	141	105	86
200	154	116	95
100	170	127	104
0	187	140	114

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