An Evaluation of Right-Turn-In/Right-Turn-Out Restrictions in Access Management

Final Report

Submitted to:

Michigan Department of Transportation

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16. Abstract

Access management strategies are devised to facilitate travel mobility and improve safety. Direct access especially left-turns in and out of developments can create significant problems for the traffic flow and safety on the adjacent roadway and at the driveways. This study evaluates the safety and operational impacts under various access configurations, and provides basic guidelines as to when left-turns at driveways should be prohibited.

The safety considerations were found to be less significant compared to the operational concerns since the crash reductions that might be expected from access restrictions appeared to be relatively modest. The importance of review of crash history by site is emphasized.

Traffic simulation models were developed using VISSIM to analyze the operational impacts of driveway turning restrictions at corner and mid-block sites. The results indicate that lesser the corner clearance, more negative is the impact on driveway related delays. Also, the negative impact due to mainline volume increment was more severe as compared to the increment in driveway volume. The impact on the driveway operations was worse when the number of lanes on the adjacent roadway was less than 5 or 4. The right-turn (in or out) driveway traffic was not critical from either the operations or safety perspectives due to fewer conflict points. General guidelines are proposed for prohibition of left-turns in and out for various combinations of mainline and driveway traffic volumes and corner clearances.

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Disclaimer

The opinions, findings, conclusions and recommendations presented in this report are those of the authors and do not necessarily reflect the official views and opinions of Michigan State University or the Michigan Department of Transportation. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

Access management strategies are devised to facilitate travel mobility and safety by controlling the spacing, location, and design of driveways, medians and median openings. Direct access to developments can create problems for the traffic flow and safety on the adjacent roadway and at the driveways themselves. This study is an attempt to study specific access issues and to explore ways to accommodate turning movements to and from developments while minimizing their negative impacts on traffic operations. Left turns in and out of developments are generally the most problematic movements in this context. One way to mitigate these impacts is to eliminate left turns, thus restricting the access to the development to "right-turn-in/out only." Turning restrictions are particularly important when the access points are relatively close to existing intersections. The impacts of such restrictions are found in several areas:

- positive impacts for main-line traffic flow immediately in and around the entrances and exits to the development where turning movements are significantly simplified, which should result in a better level of service or at least less delay;
- positive impacts from improved traffic safety which comes from elimination of several conflict points at each entrance/exit and presumably lower crash frequencies;
- negative impacts in terms of both traffic flow and safety which result from the increased difficulty for any left-turning motorist who must go "around the block" to get to or from the development;
- negative impacts in terms of access to the development (e.g., some travelers may pass on by the development rather than contend with restricted access).

In this context, the goals of the project are more narrowly focused:

- review existing guidelines for restricting access;
- assess the general magnitude of the safety impacts (e.g., number of crashes) and traveler delay that result from restricting access based on a review of the literature and state practices;

- evaluate the safety-related outcomes of right-turn-only restrictions in several specific situations where the technique has (or could have) been applied in Michigan;
- assess the traffic flow related impacts (e.g., user delay) for a variety typical situations in Michigan using traffic simulation models; and
- develop general guidelines for when the techniques should be considered.

The results of the literature review are presented first. This is followed by a detailed review of existing guidelines on access management strategies in various states; assessments of safety and traffic operations-related impacts for specified sites in Michigan; and conclusions and recommendations. Note that no attempt is made to assess or otherwise quantify the development-related economic impacts of allowing or restricting access to adjacent land uses.

REVIEW OF LITERATURE AND PRACTICE

Left turns at driveways interfere with the operation of the adjacent roadway traffic, access to adjacent properties, and cause safety problems and affect the level of service. Numerous studies have been carried out to assess how the impacts of left turns can be best mitigated. The literature review was conducted utilizing the TRIS-Online database of the Transportation Research Board (TRB), NCHRP reports, the MDOT library, and the libraries at Michigan State University.

In a report prepared for the Ohio Department of Transportation (ODOT, 2003) by the University of Dayton it was asserted that by changing driveway volumes from 50 to 200 vehicles per hour, there was no significant impact on network delay. However, changes in the mainline volume, ranging from 500 to 1200 vehicles per hour per lane, increased the network delay significantly. The recommendation was that mainline volume be used as a factor in determining the use of a direct left-turn alternative. According to the study, for an existing site if there is a potential for several driveways to lead into one development with sufficient traffic flow through the facility, left-turns could be restricted to all but one intersection. This can be accomplished through the use of right-in/right-out islands and signs. Since the latest ODOT Access Management Manual was issued in 2001, there is no readily available evidence that these findings are incorporated by ODOT.

Some studies have shown that directional median openings are generally an effective method of increasing vehicular safety and capacity. Sometimes in advance of downstream signalized intersection, mid-block directional median openings are provided to accommodate U-turns. However, there also have been concerns expressed by general public regarding the safety of U-turns. In this context, a study was carried out by Lu, Dissanayake, Xu and Williams (2001) in which they compared the safety performance of two driveway left-turn treatments—direct left-turns and right-turns-only followed by U-turns (a traveler exiting the development who want to turn left on the mainline is compelled to turn right and then make a U-turn downstream). The research team examined crash history at 258 sites in Florida with a total of 3,913 crashes over a three-year time period (1996 to 1998). The researchers found that the overall crash rate for right-turns followed by U-turns was 17.8% less than that for direct left-turns. The corresponding percentage reduction for property-damage-only crash rates was 6.4%, which was not statistically significant. The injury/fatality crash rate for right-turns followed by U-turns was 27.3% less than for direct left-turns. It should be noted, however, that providing U-turn opportunities is often not realistic—most obviously when there is no median present.

Dorothy, Maleck and Nolf (1997) in their study carried out in Michigan concluded that boulevard designs where indirect left turning strategies and signalized crossovers were typically superior to direct left-turning strategies at signalized intersections. According to the study, the boulevard designs that used direct left-turning strategies had proportionally higher amounts of delay than all other designs considered, and their operation tended to fail as the percentage of traffic volume and left-turns increased.

Chowdury, Derov, Tan, and Sadek (2005) performed a simulation analysis on prohibiting left-turn movements at mid-block unsignalized driveways. They studied the impact of varying the arterial and driveway volume on the effectiveness of restricting direct left-turns and providing alternative movements. Three different alternatives were considered for left-turn treatments at mid-block unsignalized intersections: no restriction of direct left-turns to or from the driveways; no direct left-turns in or out of driveways and diverted traffic making a U-turn at the next intersections; and no direct left-turns in or out of driveways and diverted traffic making a U-turn at mid-block. Two additional cases were also evaluated: a jug-handle design; and no direct left-turns in or out of all but one driveway (concentrated left-turn). The results showed very little operational difference between the no restrictions on direct left-turns alternative versus the restrictions with the U-turn alternative movements from site to site. According to the study, the jug-handle design appeared to be a superior alternative for accommodating left-turn deterred traffic for multi-lane divided and undivided sites compared to mid-block or intersection U-turns. It was shown that the concentrated left-turn appeared to be an effective solution for improving traffic flow conditions.

According to the NCHRP report 420: *Impacts of Access Management Techniques* (1999), travel times for right-turns followed by U-turns are comparable with travel times for direct left-turns from driveways under heavy volume conditions and when diversion distances are less than 0.5 miles. The report authors also cite studies in Florida and Michigan where eliminating direct left turns from driveways reduced crashes by about 20 percent.

Gluck, Haas, Mahmood, and Levinson (2000) conducted a study in which the impact of right-turning vehicles on the through traffic was analyzed. Twenty-two (22) sites in Connecticut, Illinois, New Jersey, and New York were studied. Each site represented an unsignalized driveway for a major traffic generator along a suburban arterial roadway without deceleration lanes. The results of the analyses were considered to be useful for establishing guidelines for deceleration lanes and spacing of unsignalized driveways. The access spacing guidelines were suggested based on operational as well as safety considerations. It was observed that for arterial right-lane volumes of 250 to 800 vehicles per hour, the percentage of through vehicles impacted was about 0.18 times the right-turn volume. It was suggested that this criterion can be used as a basis for providing right turn lanes.

In an Ohio-based study, Thieken and Croft (2004) evaluated the characteristics that impact violation rates at right-in/right-out driveways. The research was focused exclusively on right-in/out driveways with no center median on the highway to prohibit left-turns. Relevant characteristics related to violations included the shape and size of the raised island, existence of vehicle storage on the arterial, existence of delineators on the island, and the volume of traffic on the arterial.

A survey was developed by Chowdhury (2004) and sent to the 50 state transportation agencies to inquire about their policies and procedures to assess the standard practice of restricting direct left-turns from driveways, and to examine the use of alternatives to direct left-turns. Analysis of the results revealed a lack of standards in most states. Only a few states had implemented a formal policy for controlling left-turn treatments at driveways. Analysis of the survey results showed that midblock U-turns and jug-handles have been successfully implemented.

It is generally agreed that driveways should be placed sufficiently away from the main intersection to avoid conflicts with the adjacent traffic flow and the intersection-related queues. AASHTO advises that driveways not be permitted within the functional area of an intersection; therefore there should be sufficient corner clearance to separate access connections from roadway intersections. The issue is also addressed in the Access Management Manual (TRB, 2003) and it is advised to allow construction of an access connection in case of no other alternatives along the property line, farthest from the intersection. In such cases, agencies typically reserve the right to require directional connections (i.e., right-in/out, right-in-only, or right-out-only), or to require nonconforming corner properties to share access with abutting properties.

A study on full versus directional median openings was conducted in Florida by Dissanayake and Lu (2003). It was found that by converting a full median opening into a directional median opening, a significant reduction occurred in weighted average delay experienced by left-turning vehicles whereas total travel time remained unaffected. However, the safety effects of the conversion were highly significant. The conflicts per hour were reduced by 49.9 percent and conflicts per thousand vehicles were reduced by 46.3 percent.

In addition to corner clearance, driveways should be properly spaced to ensure safety. According to Transportation Research Circular 456 (1996), spacing of driveways and streets needs to reflect sound traffic engineering principles, driver behavior, and vehicle dynamics. Spacing should consider influences such as highway function, access class and speed, volume of trucks, separation of conflict areas, the number of conflict points, and locations of upstream and downstream driveways. The recommended spacing values provided by this research circular range from 120-1875 ft, depending on the speed range of 20-60 mph.

Other design standards like driveway width and corner clearance are also of concern. The Access Management Manual (TRB, 2003) recommends driveway width ranging from 25-40 ft depending on different design conditions. NCHRP Report 420: *Impacts of Access Management Techniques* (1999) provides minimum corner clearance values required for certain speeds. These are summarized in the spreadsheet in appendix 1.

In concluding the literature review, it is found that there have been few or no studies specifically regarding examination of turn restriction policies at driveways; however several studies have been conducted to find alternatives for left-turn deterred traffic. Most researchers have found right-turn-only followed by U-turns are better and safer option than direct left-turns. Furthermore, there are no overarching national standards or guidelines for restriction to turning movements at driveways. The development of uniform standards for Michigan to accommodate left-turn deterred traffic and for driveway-related access management would be extremely beneficial for improvement of traffic flow and safety at the driveways.

SAFETY-RELATED ASPECTS OF TURNING RESTRICTIONS

Left-turning movements to and from the driveways are usually considered to be the most problematic in the context of driveway-related crashes. To understand the nature of driveway-related crashes, Jonathan and Gattis (2008) performed a study on driveway collision patterns in a low-density urban environment. A detailed examination of over 2,000 accident reports was performed to identify driveway-related crashes. The findings of the study provided insight into which maneuver patterns and situations are more problematic, and the relative risk for different user groups, both in terms of frequency and severity. The research revealed that higher proportions of collisions were linked to left-turn maneuvers and use of two-way left-turn lanes.

Several other research studies have also been conducted on the nature of accidents that occur at driveways. In particular, Paul Box and Associates (1998) performed three studies on hundreds of crashes at more than 1,300 driveways in three different communities in Illinois and found that left-turning vehicles (exiting and entering) are involved in the majority of driveway-related crashes. The description of crashes at commercial driveways by turning movement that was found in this study is presented in table 1.

Table 1. Crash involvement percentages at commercial driveways (Box, 1998)

Turning movement	Percent of total crashes at commercial driveways
Left-turning vehicles:	
Entering business driveways	43% to78%
Exiting business driveways	14% to 31%
Right-turning vehicles:	
Entering business driveways	6% to 15%
Exiting business driveways	2% to 15%

According to the literature noted in the Access Management Location and Design Participant Notebook (NHI year), 74% of driveway accidents involve left-turn maneuvers. Of these accidents, 47% are associated with left turn-in maneuvers as shown in figure 1.

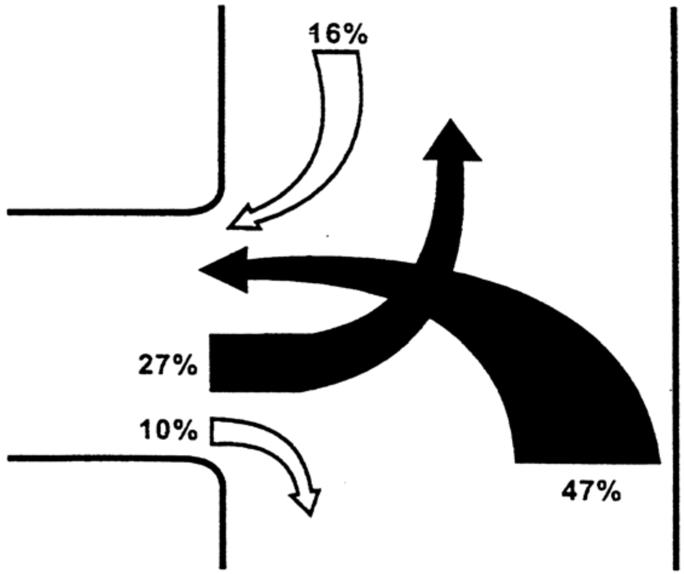


Figure 1. Percentages of driveway crashes by movement (NHI year)

According to the FHWA's Technical Guidelines for the Control of Direct Access to Arterial Highway, a typical right-in/right-out channelization warrant on undivided highways is that with speeds of 30-45 mph, ADT greater than 5,000 vpd, and driveway volumes of at least 1,000 vpd, it is required to prohibit turns around 100vpd in number. Table 2 shows annual accident reductions per driveway for restricting both left turn-in and -out maneuvers.

Table 2. Annual accident reductions per driveway for restricting both left-turn-in and out maneuvers (FHWA year)

Driveway Volume (vpd)	Highway ADT (vpd)		
	Low <5,000	**Medium 5000-15,000**	**High >15,000**
Low<500	0.13	0.23	0.31
Medium 500-1,500	0.31	0.55	0.75
High>1,599	0.49	0.85	1.15

Safety Effects of Prohibiting Direct Left-Turns

In order to address the operational and safety issues related with direct left turns, traffic engineers have often looked at other alternatives of facilitating left turns– one of which is right turns followed by U-turns (indirect left turns). Castillo (2002) looked at the safety-related performance of direct left turns from a driveway compared to right turns followed by U-turns. Results of a before-and-after study conducted at a site where a direct left turn from a driveway was converted to a right turn followed by U-turn showed significant and positive effects in terms of roadway crashes due to a lesser number of conflicts. Figure 2 shows the movement of a right-turn followed by a U-turn.

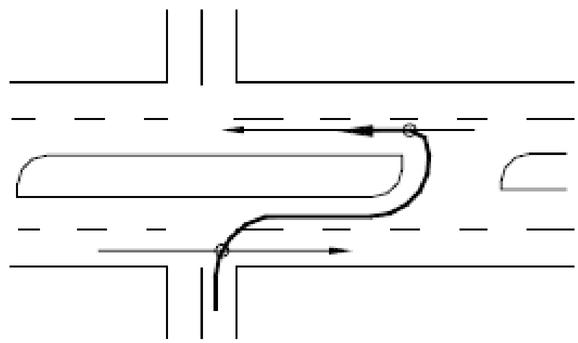


Figure 2. A right-turn movement followed by a U-turn (Huaguo et al. 2000)

Other researchers have also found that the prohibiting left turns and providing alternative treatment such as right turn followed by U-turn (through directional median opening) is effective in increasing vehicular safety and capacity. Figure 3 shows the typical arrangement of directional median opening for prohibiting direct outbound left-turns from driveway. Lu et al. (2001) carried out a safety study of two driveway left-turn treatments: direct left-turns and right-turns followed by U-turns were compared. The research team examined crash histories at 258 sites in Florida with a total of 3,913 crashes over a three year time period (1996 to 1998). The findings were that the overall crash rate for right-turns followed by U-turns was 17.8% less than that for direct left-turns. The corresponding reduction for property-damage-only crash rates was 6.4%, which was not statistically significant. The injury/fatality crash rate for right-turns followed by U-turns was 27.3% less than for direct left-turns.

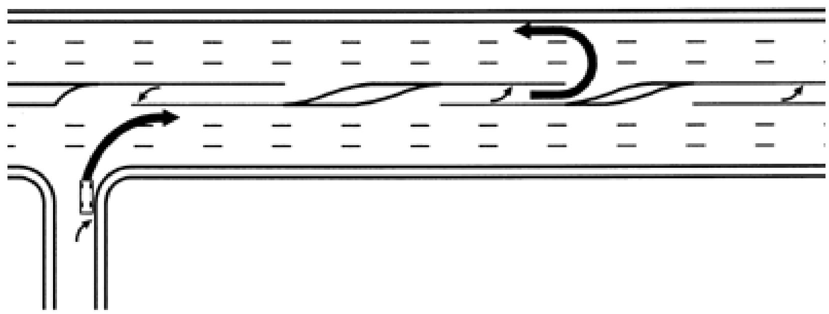


Figure 3. Concept of directional median opening (FHWA 2004)

Safety Effects of Right-In/Right-Out Driveways within the Functional Area of the Intersection

The performance of "right-in/right-out" restriction technique has been found to improve the safety at adjacent roadway especially when the driveway is too close to or in the functional area of the intersection. The functional area is that area near intersection that includes auxiliary lanes on roads. Box (1998) presented the effects of intersections on driveway accidents. The research included a detailed tabulation of over 15,000 accidents in two Illinois suburbs. The crashes were distributed on the basis of type, location (intersection versus midblock conditions) and functional classification (major, collector, and local). Neither of the cities placed any limitation on driveway proximity to intersections, other than clearing the corner radius. Based on his findings, Box suggested that access management policies regarding restricting driveways closer to intersections is a better and safer option than providing the access point at a certain specified distance from the intersection. Figure 4 shows the concept of right-in/right-out restriction in the functional area of intersection.

TRB's Access Management Manual (TRB 2003) also addresses this issue and suggests only allowing a driveway access point in cases where there are no other alternatives along the property line, farthest from the intersection. In such cases, agencies typically reserve the right to require directional connections (i.e., right-in/out, right-in-only, or right-out-only) or nonconforming corner properties to share access with abutting properties.

While restricting the access to right-in/right-out, it is equally important to provide an appropriate channelization to restrict prohibited movements as insufficient channelization could provide enough space to invite prohibited turns. Thieken and Croft (2004) carried out a study in Ohio on the evaluation

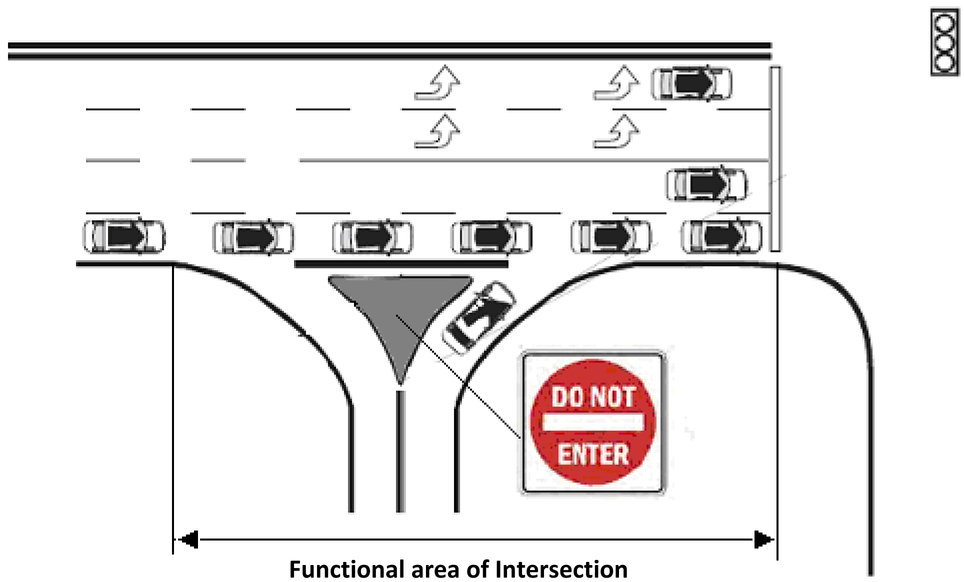


Figure 4. Restricting driveway to right-in/right-out in the functional area of intersection

of characteristics that impact violation rates at right-in/right-out driveways. Their research focused exclusively on right-in/right-out driveways with no center median on the highway to prohibit left-turns. They collected data at seven right-in/right-out sites and performed linear regression analysis to evaluate the nature of relationships between violations and right-in/right-out driveway and site features. Their analysis results were not conclusive but pointed some important characteristics as causes of violations including the shape and size of the raised island, existence of vehicle storage on the arterial, existence of delineators on the island, the volume of traffic on the arterial, visibility of alternate legal left-in/left-out facility and signage at the driveway.

Review of Practice

An attempt was made to identify and review access management documents (including manuals and publications) for all states in order to determine different standards, guidelines, and/or rules for controlling turning movements at driveways (e.g., when to allow/restrict driveways; how to control them; and design standards for driveway width, spacing, and corner clearance). Such information was found on-line for 31 states. While most of these states have provided their design standards for driveways, only a few appear to have implemented a formal turn-restriction policy. A summary showing the number of states that provide the required information, including their criteria and design standards, is provided in figure 5 with more detail in figure 6. Detailed information from all available

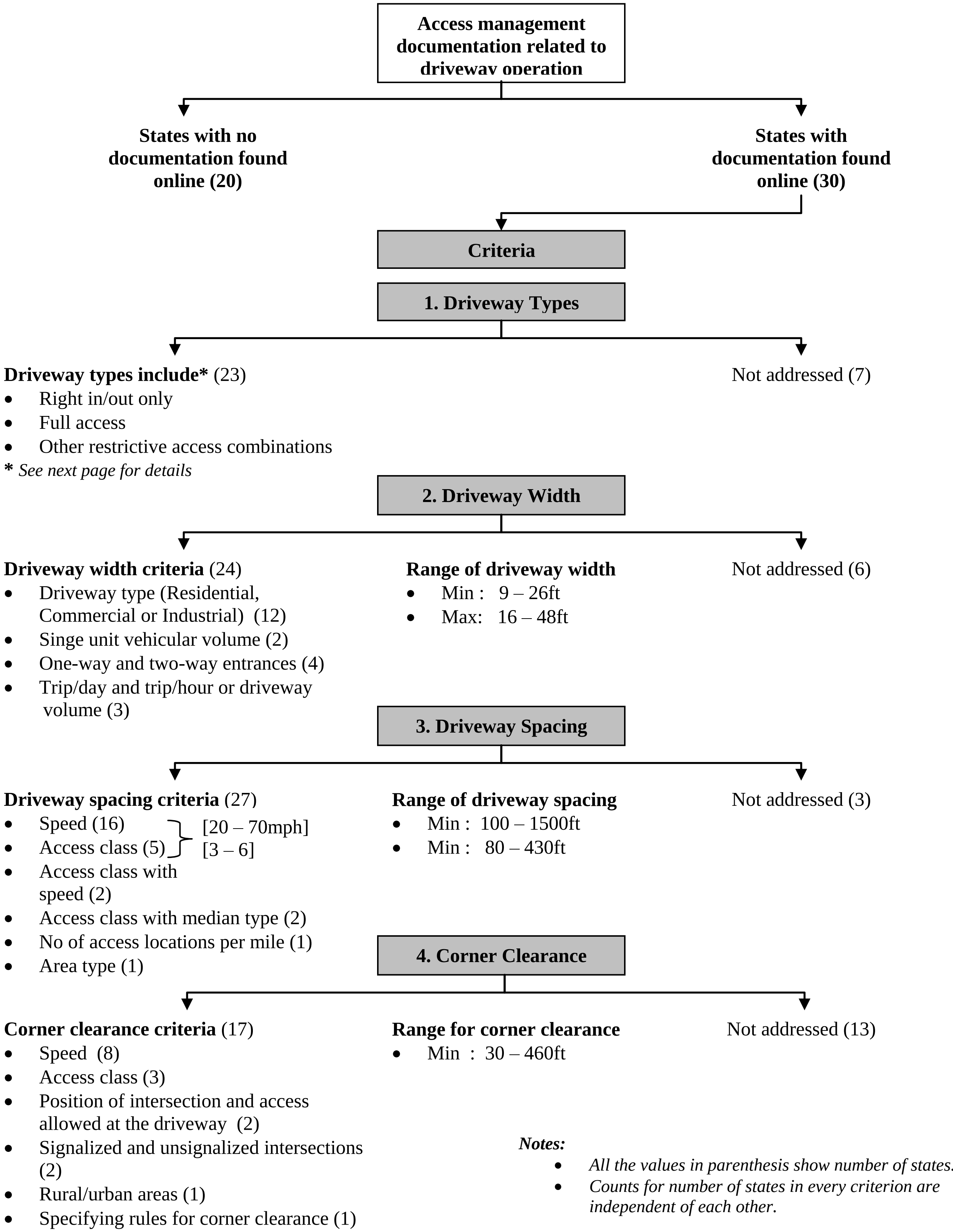


Figure 5. Summary of Turn Restriction Policies

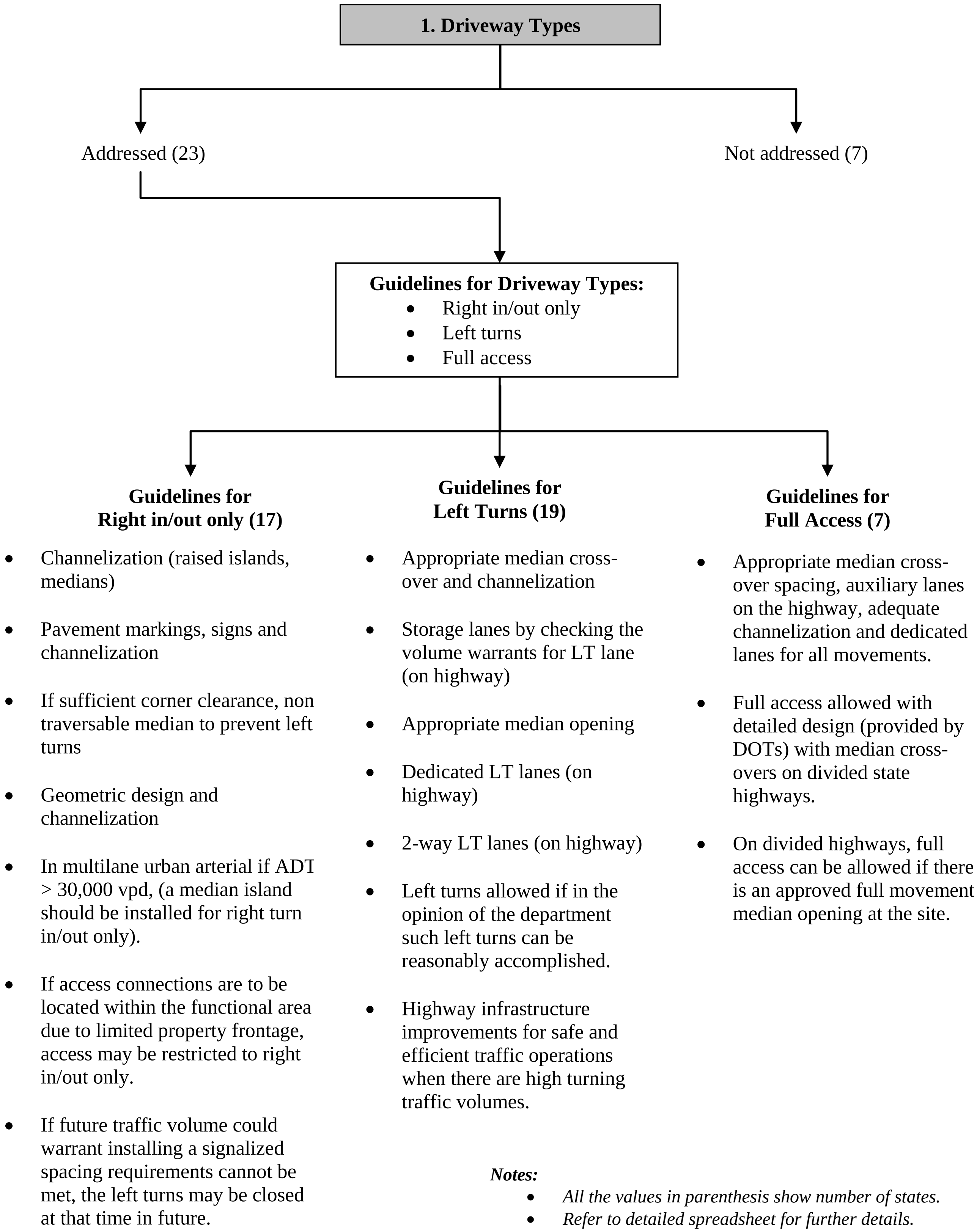


Figure 6. Summary of Guidelines for Driveway Types

state documentation including turn restriction guidelines and design standards of driveways is provided in appendix 1. A summary of those materials follows.

Colorado suggests restricting certain turning movements at driveways by channelized islands if the driveway volume is predicted to exceed 100 DHV (design hourly volume). Left-turns are allowed on an undivided highway by the approval of the permitting authority.

Delaware and Kansas do not address when to provide right-in/out only driveways but recommend proper channelization to control these types of driveways. Delaware allows left turns where the design meets all safety requirements (although it's not clear what these include). It also recommends median crossover and channelization to control for both right and left turns. Kansas also suggests modifications in median crossovers to accommodate projected traffic movements.

Seven states including Florida, Idaho, Kentucky, North Carolina, Texas, Utah, and Virginia have similar guidelines for right-in/out-only driveways. According to these states, when sufficient corner clearance cannot be provided or if access connections have to be located within the functional area due to limited property frontage, the access may be restricted to right-in/out only or other limited movement treatments. Texas addresses this issue along with connection spacing. According to Texas guidelines, it is also important to maintain adequate connection spacing and if it cannot be achieved then lesser spacing for a shared access with an abutting property may be allowed. In case of no other alternatives, Texas allows the access location along the property line farthest from the intersection but to ensure safety under these conditions, it recommends allowing only the right-in/out turning movements if feasible.

The Access Management Manual (TRB, 2003) provides similar guidelines in this context. It suggests that there should be sufficient corner clearance to separate access connections from roadway intersections. In case of no other alternatives, it recommends allowing the access connection as far as possible from the intersection but in these cases agencies typically reserve the right to restrict driveways as right-in/out, right-in only or right-out only.

According to Indiana, major driveways into developments such as shopping centers should be constructed to prevent cross traffic movement of internal traffic within 100 ft from the highway edge of pavement. This may be accomplished by the use of a raised island. In context of left-turns, the state guidelines recommend dedicated left-turn lanes on the driveway and left-turn deceleration lanes on the highways for required level of service above “C.” For high volume traffic generators such as shopping centers, industrial plants, industrial parks, residential projects, and similar developments may have a median crossover desirable.

Iowa suggests that median openings should not be permitted except to accommodate large traffic-generating facilities such as large shopping centers or industrial plants. Median openings may be permitted in these instances if adequately justified (again, undefined) to account for turning movements.

Maryland recommends using commercial right-in/right-out driveways on all divided highways with posted speeds above 40 mph. For urban street environments where posted speeds are 40 mph or lower and a narrow raised median separates the directional highways, it allows use of other commercial driveways as long as appropriate signing is provided to discourage errant movements.

Minnesota addresses this issue for existing roadways and recommends limiting the entrance to right-in/right-out only, unless weaving or other traffic operations indicate the need for further restrictions on turning movements (e.g., right-in only or right-out only). It also suggests limiting access to right-in/right-out movements on planned highways where a median is to be constructed.

New Jersey provides two scenarios to restrict left turns: if future traffic volumes warrant installing a traffic signal and signalized spacing requirements cannot be met, at such time left-turn access may be closed; and if an undivided highway becomes divided as a condition of the access permit, left-turn access may be closed. In both cases, access should be closed for left-turns in accordance with the standards provided by the New Jersey Access Management Code.

New Mexico suggests restrictions to full left-turn access when there are issues related to safety or operational deficiencies that would be expected if a full access median was implemented. Geometric design and channelization should be used to restrict undesirable movements.

According to Ohio, left-turn movements shall not be permitted if a median is already established and the opening of the median would not provide, in the determination of the Department, any significant operational or safety benefits to the general public or would be counter to the purpose of the median construction and the continued function of the highway at the category assigned to it.

Pennsylvania implements turn restrictions if the improvements that would be required at a driveway to achieve acceptable levels of service cannot be provided due to constraints, or if there is a history of high crash rates due to left-turning vehicles. For high and medium volume driveways, channelization islands and medians shall be used to separate conflicting traffic movements into specified lanes to facilitate orderly movements for vehicles and pedestrians.

Vermont permits one or both left-turn movements at the access point if the applicant establishes to the agency's satisfaction that left-turn movements would not create unreasonable congestion or safety problems, or lower the level of service below the agency’s policy.

In Washington, all private access connections are for right-turns only on multi-lane facilities unless there are special conditions and the exception can be justified.

Wyoming’s recommends installing a median island on multi-lane urban arterials if the ADT is more than 30,000. In this case, direct access would be right-in/right-out only and they should be provided with right-turn deceleration lanes.

Several states, including Georgia, Maine, Michigan, West Virginia, and South Dakota generally indicate that raised islands or channelization are effective in controlling right-in/out-only driveways. On the other hand, left turns can be accommodated with proper median opening design. Maine also suggests two-way-left-turn-lanes onto a mobility arterial to accommodate left-turns.

From the review of state practices, it can be concluded that there are not unique criteria that are followed by all or most states for right-turn-in/right-turn-out restrictions in their access management policies. Most of the states that address this issue provide different criteria to restrict turning movements, which include level of service, average daily traffic, and crash history. A few states which provide somewhat similar scenarios recommend providing right-in/out only driveways when there is insufficient corner clearance and there is no other alternative. This practice is also recommended by the Access Management Manual (TRB, 2003). Almost all the states which provide any guidelines in relation to turn restrictions recommend proper channelization to restrict undesirable movements into or out of the driveways, and adequate median crossover design to accommodate left-turns if required. Even the states which have developed criteria related to access control are often vague with respect to defining specific thresholds that are appropriate for when access should be restricted.

ANALYSIS OF SAFETY AND OPERATIONAL IMPACTS OF TURN RESTICTIONS IN MICHIGAN

In the context afforded by the review of the literature and state practice in restricting turning movements at development access points, several sites in Michigan were identified for detailed study. As noted previously, the latter consisted of an analysis of crash histories before and after turning restrictions were implemented and an analysis of operational impacts. The actual study sites were selected by MDOT and were then supplemented with a selection of similar sites for comparison purposes. Crash analysis was then done on all sites. Operational impacts were studied using a micro-level traffic simulation software package—VISSIM. The point of these two analyses was to identify when turning restrictions should be implemented from traffic safety and operations perspective. More details on these two approaches, as well as the results, are provided in the following sections.

SITE SELECTION

A total of eleven (11) sites with recently-implemented access control (e.g., left turns in/out prohibited) were identified by MDOT, out of which nine (9) were selected for detailed study. The list of project sites is provided below and more-detailed descriptions are in appendix 2.

- Site 1: MSU Federal Credit Union, W. Saginaw Street, Lansing
- Site 2: Walgreens, W. Saginaw Street and Creyts Road, Lansing
- Site 3: Rite Aid, SE corner of M-36 and Dexter Road, Brighton
- Site 4: Walgreens, M-21 and Linden Road, Flint
- Site 5: Krispy Kreme, M-21, Flint
- Site 6: Tim Hortons, M-57, Clio
- Site 7: BP Gas Station and fast food restaurants, M-21, Lennon
- Site 8: National City Bank and Advance Auto, US-12 (Chicago Road) and Michigan Avenue, Coldwater
- Site 9: Family Video, M-66 (Capital Ave) and Emmett Street, Battle Creek

The main objective of the preliminary site visits was to get a general sense of problems at individual sites, and to perform preliminary data collection. Manual data collection forms (see appendix 3 for details) were developed and modified to fit specific sites based on these observations. All data were collected during February-April, 2008. During follow-up visits, the following types of data were collected:

1) manual traffic counts using data collection sheets;
2) traffic volume and turning counts using counters (Traffic Data Collector, TDC-12, Jamar Technologies, Inc.); and
3) video-tape recordings.

These data were used to better understand what was going on at the site (e.g., were motorists ignoring turning restrictions) and provide the data necessary to examine operational impacts of the various turning treatments at geometrically different sites using the traffic simulation software (VISSIM).

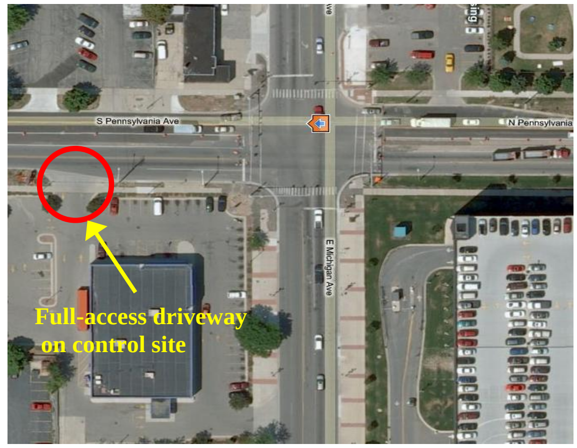
The sites are presented and discussed one-by-one in the following paragraphs. In each instance, a picture of the MDOT-identified site is presented along with a similar site. Initially, it was thought that a classic "before-after with control" study could be done on all of the sites. As work progressed, numerous problems cropped up including differences among the selected sites, difficulty in identifying true control sites, unknown time windows for changes in access, unknown prior land uses, and significant variation in variables that could be used to classify sites (e.g., ADT). Thus, the sites selected are termed as "similar" (rather than "control"), and the crash analysis is qualitative rather than statistical in nature.

SAFETY IMPACTS

As just noted, sites are presented one by one and introduced with some general comments. In each case the sites were identified and an indication of when the access control change was implemented. Electronic crash records were then retrieved from the statewide crash database. Once these crashes were identified, hard copies were also retrieved so that a better understanding of the crash circumstances could be obtained (i.e., through review of the crash-scene sketches and hand-written comments). More detail is provided for the first site in order to better illustrate this procedure.

Site 1: Walgreens, W. Saginaw Highway and Creyts Road, Lansing (corner site; before intersection)

(a) study site

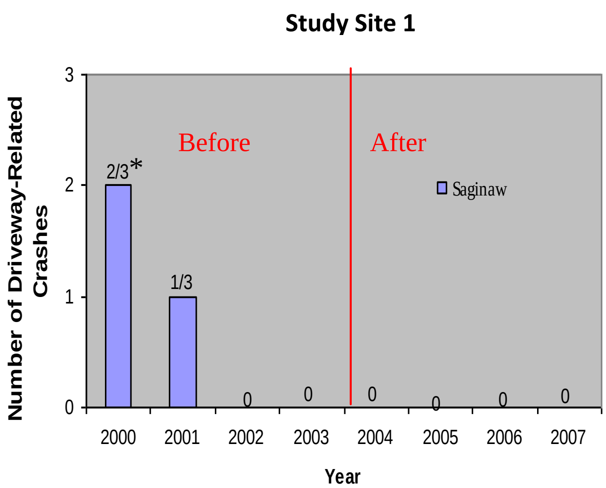


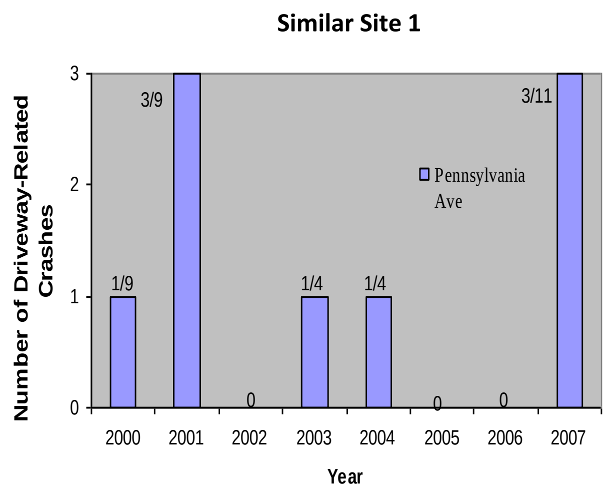
(b) similar site

The first site is located in the southwest (SW) quadrant of Saginaw Highway and Creyts Road in Lansing. The land use was changed to Walgreens in 2004 with a full access driveway on Creyts Road and a right-in/right-out-only driveway on Saginaw. The right-in/right-out driveway is provided with a raised island and narrow driveway lanes to prohibit left turns (in and out), but drivers were observed using this driveway to turn in and out of the development illegally. There is a right-turn auxiliary lane at the intersection. ADT on Saginaw is 33,200 vpd according to 2007 traffic counts which is considered to be high volume (FHWA's definition of high volume is adopted here: ADT>15,000 vpd). Corner clearance for this driveway is 209 ft which is below the MDOT's stated minimum standard of 230ft. However, the driveway is located at the farthest point (on the property) from the intersection.

The "similar site" is located in the SW quadrant of Pennsylvania and Michigan Ave in Lansing. The development is a pharmacy of almost the same size as that of the study site. Driveways on both the roads providing access to the development are full access. Pennsylvania Ave (with the driveway of interest) is a busy street (ADT=19,857 vpd) as it serves as a major route for traffic to Sparrow Hospital and Eastern High School. This site seemed somewhat comparable to the study site.

The "window" for tracking crashes is 2000-2007 (3-4 years on either side of the year of the change). As part of the crash analysis, driveway-related crashes were broken out of the total crash frequency and reported in the following figures and summary tables. In the bar charts driveway-related crashes are reported and also shown as a fraction of total crashes in the area. The analysis of this site showed crashes involving left-in and out movements before 2004. The driveway-related crash frequency was found to be 3 crashes in four years at the driveway on Saginaw. As all crashes reported at the driveway involved left-turning movements, it can be assumed that the driveway on Saginaw Hwy might not been restricted earlier because no evidence of turning violations was found on the crash reports.





* The number in the numerator is the number of driveway-related crashes; the denominator is total crashes

Site	Type of Access	Adjacent Road	Time Span	Total Crashes on the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 1	RIRO	Saginaw Hwy	Before 2004	16	3	18.8
			After 2004	15	0	0
Similar Site	Full Access	Pennsylvania Ave	2000-2007	58	9	15.5

The other crashes at the site (i.e., those not driveway-related) were primarily rear-end crashes. Further details can be found in appendix 4. Considering the above, it appears that restricting the access to right-in/right-out has contributed to improving the safety at Saginaw Hwy by reducing the number of crashes.

During the data collection, it was noted that turning movements are controlled by a small channelization island at the driveway entrance to provide restrictions for left-turn movements; however illegal left turns (in and out) were made frequently although presumably not as often as they would have been without the channelization. There was no sign on the island indicating turning prohibitions. Thus, the reduction in turning-related crashes is in spite of the prohibited maneuvers.

Site 2: MSU Federal Credit Union, W. Saginaw Highway, Lansing (mid-block site)

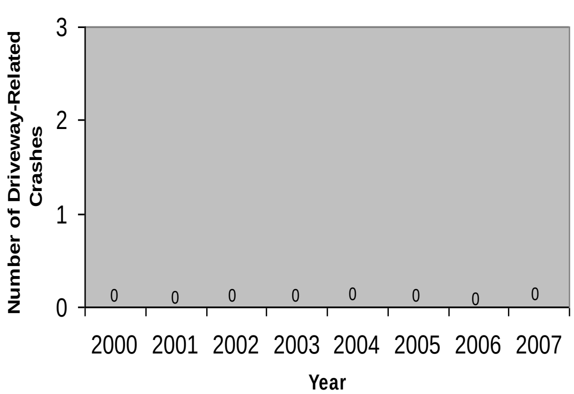
(a) study site

(b) similar site

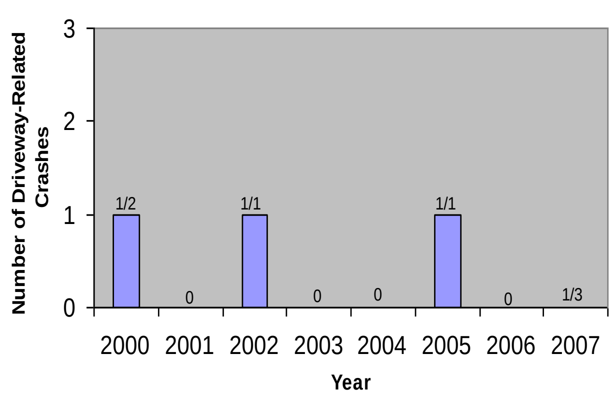
This is a mid-block site, well beyond the influence area of the next downstream (signalized) intersection. The driveway is a main driveway leading to a commercial area (not just the MSU FCU). The driveway is restricted by a small channelization (and signed for outbound traffic) to restrict left turning movements. The information about the changes that occurred to the site was neither found by MDOT nor in the UD-10 reports. The channelization seems to be insufficient to deter drivers from making left turns (in and out) as they were frequently observed to run over (literally) and around the island during the site visits. The ADT on Saginaw is 28,100vpd and, so, classified as a high-volume site.

The similar site is a Comerica bank at a mid-block location on N. Grand River Avenue (near Bardaville Drive) in Lansing. ADT on Grand River is 17,100vpd, less than on Saginaw but still comparable in the sense that it is also “high volume.” The driveway is a full-access, allowing both left turns in and out and also provides access to other land uses.

Study Site 2



Similar Site 2

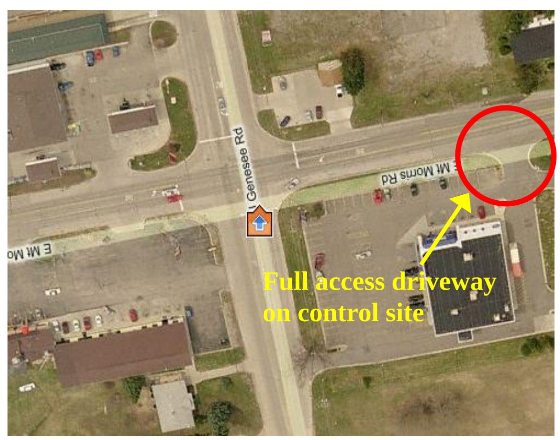


Site	Type of Access	Adjacent Road	Total Crashes at the Adjacent Road	Driveway Related Crashes	
				#	%
Study Site 2	RIRO	Saginaw Hwy	9	0	0
Similar Site 2	Full Access	Grand River Ave	7	3	42.8

Even with the insufficient channelization and frequent left-turning violations which could be safety hazards, no crashes were reported at this driveway in the past eight years. However, a few rear-end crashes and other driveway-related crashes occurred in the vicinity of this site. As frequent left turning violations were observed at the site along with the vehicles running over the island, the insufficient channelization at this driveway could be a potential safety hazard. The analysis of the similar site showed 7 crashes at this site in the past eight years, of which 3 were driveway-related involving the left-out movement from the driveway (despite the lower mainline volume).

Site 3: Rite-Aid Pharmacy, M-36 (E Main Street) and Dexter Road, Pinckney (corner site; after intersection)

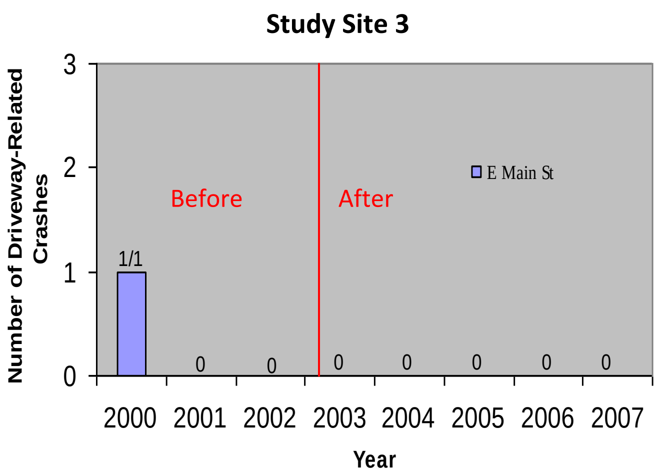
(a) study site

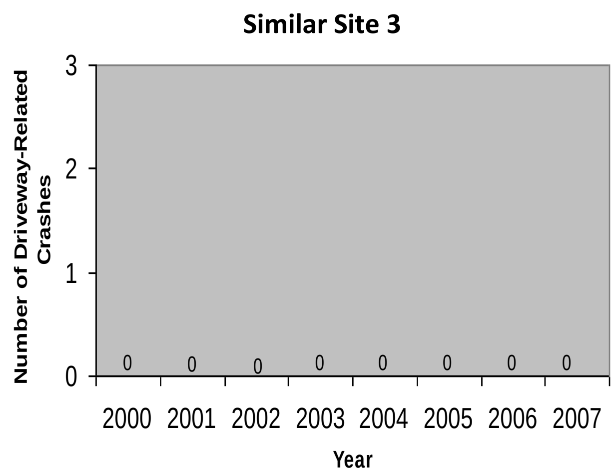


(b) similar site

This site is located in the SE quadrant of Dexter St and M-36 (Main St) and was changed to a Rite Aid Pharmacy in 2003. The site is in a small town so the traffic volume is not high (ADT=11,210 vpd on Main St). While this is a corner site, the driveway is AFTER the intersection and, so, different from site 1. The driveway is restricted to right-in/out-only and close to the intersection (although at the farthest point on the property).

The similar site is at the intersection of Genesee and Mt Morris Rd in Mt Morris and is also a Rite Aid Pharmacy. The driveway is full access. It is also located in a less urbanized area. The ADT on Mt Morris Road is 5,390 vpd and, so, reasonably comparable to the study site.





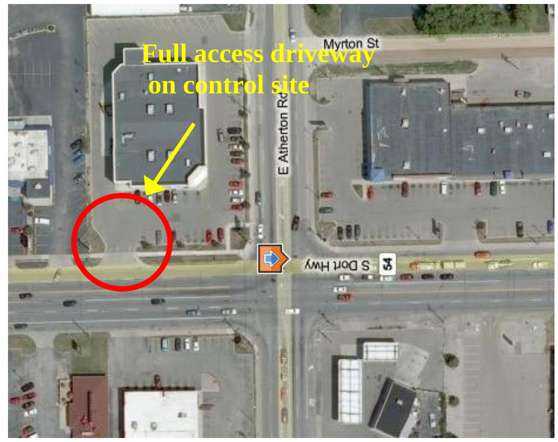
Site	Type of Access	Adjacent Road	Time Span	Total Crashes at the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 3	RIRO	E Main St	Before 2003	2	1	50
			After 2003	11	0	0
Similar Site 3	Full Access	Mt Morris Rd	2000-2007	14	0	0

The crash analysis at the study showed that there was only one driveway-related crash in the before period and none during the after period. The similar site had no driveway-related crashes during the entire time window.

As far as the type and severity of crashes is concerned in the vicinity of the site, some rear-end crashes had been reported every year at E Main St while on Dexter St. In addition to the rear-end crashes, angle crashes were also observed. Most of the crashes at the site were found causing property damage only.

The lack of driveway-related crashes at this site implies that turning restrictions may not be so critical in lower-volume situations and/or when the development is located after the intersection, notwithstanding the other crashes that are occurring.

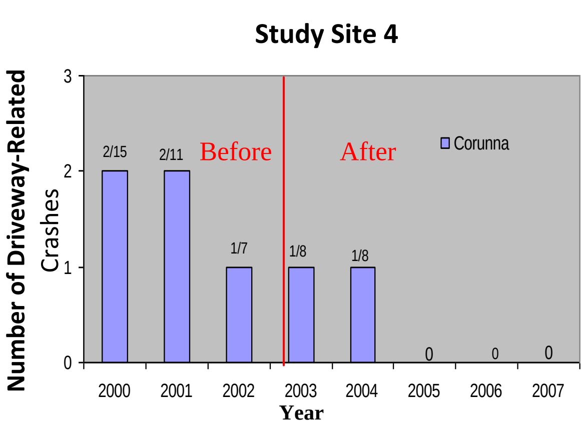
Site 4: Walgreens, Corunna Road (M-21) and Linden Road, Flint (corner site; after intersection)

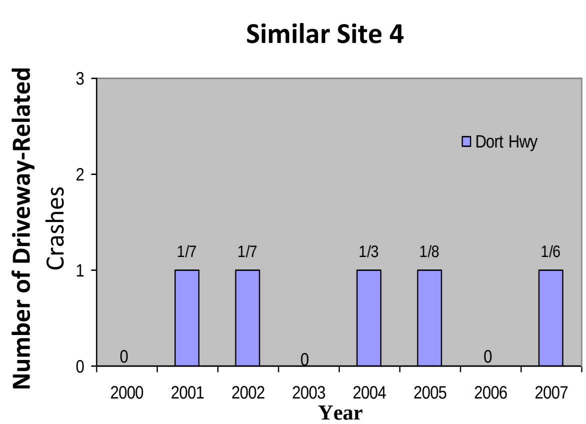


(a) study site (b) similar site

This site is located in the NW quadrant of Corunna and Linden Roads in Flint. Before 2003, the development was a bank and the driveway at Corunna Rd was full access and closer to the intersection than it is now. The current development (Walgreens) has a restricted (right-in/out-only) on Corunna Road. The restricted driveway is signed to further "enforce" the channelized driveway: "Right Turn Only" and "Do Not Enter" signs were used to permit outbound right turns and to restrict outbound left turns respectively; another "Do Not Enter" sign was used to restrict inbound left turns. The ADT on Corunna is 18,400 vpd,

The similar site is a Walgreens at E Atherton Road and S Dort Highway in Flint. In this instance the driveway is full access. Dort has an ADT of 20,800.





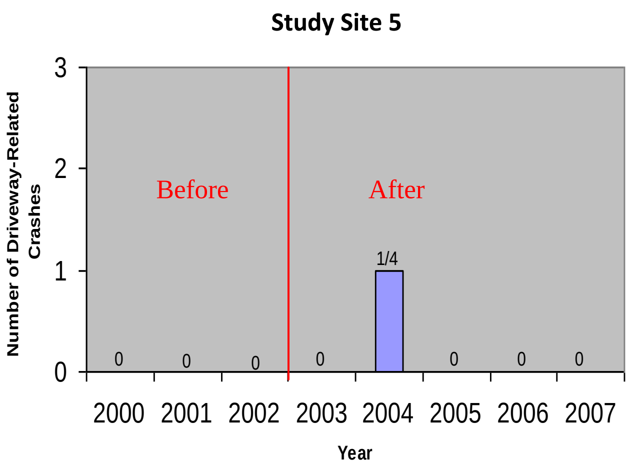
Site	Type of Access	Adjacent Road	Time Span	Total Crashes at the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 4	RIRO	Corunna Rd	Before 2003	33	5	15.1
			After 2003	29	2	6.9
Similar Site 4	Full Access	Dort Hwy	2000-2007	53	5	9.4

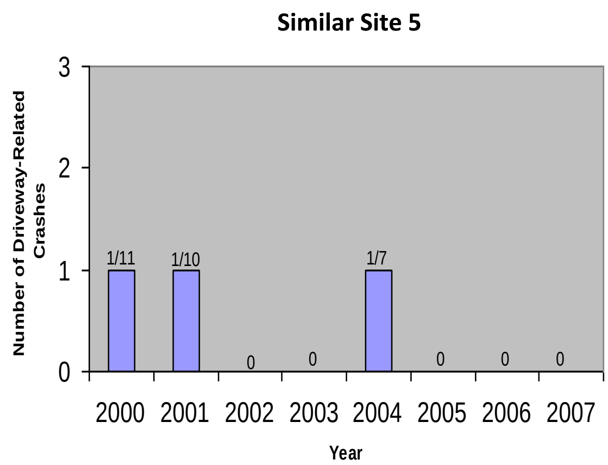
In this instance, results showed a significant number of driveway-related crashes involving left-out movements over the period. After 2003, when the site was changed to Walgreens and presumably the driveway at Corunna Rd was restricted to right-in/right-out, there was a decrease in crashes at the restricted driveway. Since the land use was known to have changed, ITE trip generation models were used to check the likely changes in driveway volumes. The former land use was a bank which, according to the trip generation software, would have almost three times as much driveway-turning volume. Thus, some of the decrease in driveway crashes could also be due to the decrease in the turning volumes and related conflicts. A separate examination (not shown) of the driveway on the cross street indicated that the crash frequency at the full access driveway on Linden Rd didn't decrease and in fact after 2003 both left-in and out movements from this driveway had been causing crashes. Comparison of the trend at the study site (Corunna Road) to that at the similar site (Dort Highway) showed that the latter had relatively similar performance over time. In general then, the evidence at this site points to potentially mixed results relative to the efficacy of changing the access control at the study site. However, it is clear that, at a minimum, there was no increase in crashes as a result of the change.

Site 5: Krisy Kreme, M-21 (Corunna Road), Flint (mid-block site)

(a) study site (to the left) and (b) similar site (to the right)

This is a mid-block site where both the study and similar sites are on the same segment of highway and not too far apart. Notwithstanding potential rush-hour directional shifts, the traffic conditions should be quite similar. The study site was changed to Krispy Kreme in 2003. The driveway of this site is properly restricted with raised island and signage to prohibit left turns (ins and outs). Some violations of the turning restrictions were noted during data collection. This similar site is located just about 1000 feet away on the opposite side of the road. The development at the similar site is a fast-food restaurant (Wendy's) and has been present since at least 2001 (verified by information found in the UD-10 reports). According to ITE trip generation models, the generated traffic for both land uses is comparable but a little higher in PM at fast-food restaurant. The driveway allows full access. ADT on Corunna Road is about 27,200 and can be considered as a high volume arterial (according to FHWA definition of high volume ADT $\geq$15,000).





Site	Type of Access	Adjacent Road	Time Span	Total Crashes at the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 5	RIRO	Corunna Rd	Before 2003	9	1	11.1
			After 2003	20	0	0
Similar Site 5	Full Access	Corunna Rd	2000-2007	51	3	5.8

[check numbers above and in bar charts]

The crash analysis showed just one (1) left-turning-related crash in the past eight years at the driveway at the study site, and that was during the after period. Similarly, there really are only a few turning-related crashes at the similar site. The crash analysis at this site shows quite neutral impacts of changing the access control.

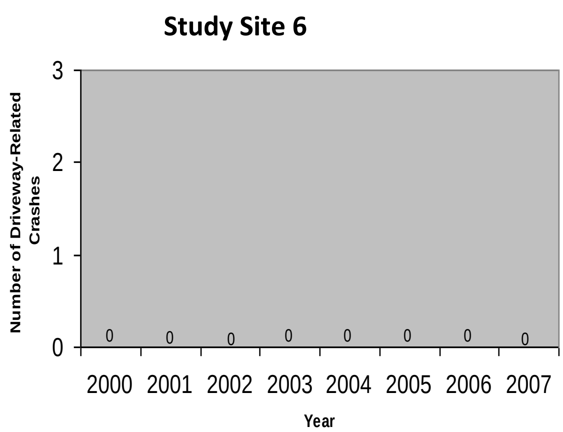
Site 6: Tim Hortons, M-57 (Vienna Road), Clio (mid-block site)

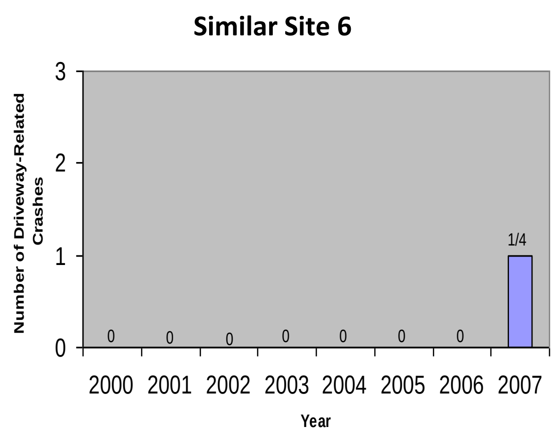
(a) study site (to the right) and (b) similar site (to the left)

The driveway providing access to this mid-block site is restricted for outbound left turns only. Thus, this restriction is different from the other study sites. (However, there were no such restrictions for adjacent developments.) In addition, the information regarding land-use change that occurred at the site was not found in the accessible resources (i.e., it is not clear when access restrictions changed). Some prohibited left turns were observed during data collection periods. The similar site is located on the same road ~ 750 ft away from the study site. The driveway providing access to the similar site is restricted for left-turn movements (inbound and outbound). The ADT on Vienna Road is 38,140.

No driveway-related crash was reported at the study site in the past eight years, and only one was noted at the similar site. Moreover, the latter involved an illegal "left" turn but appeared (from the UD-10 sketch) to involve a vehicle attempting to go more-or-less straight across the highway to a land use on the other side (a somewhat atypical movement).

Because of the different access restrictions as well as the lack of driveway-related crashes, neither the study nor the similar site are really comparable to the other sites. However, the paucity of crashes in and of itself suggests that turning restrictions at mid-block locations (even on high volume streets) may not be critical from a safety perspective.





Site	Type of Access	Adjacent Road	Total Crashes at the Adjacent Road	Driveway Related Crashes	
				#	%
Study Site 6	Restricted for left-out	Vienna Rd	17	0	0
Similar Site 6	Full Access	Vienna Rd	14	1	7.1

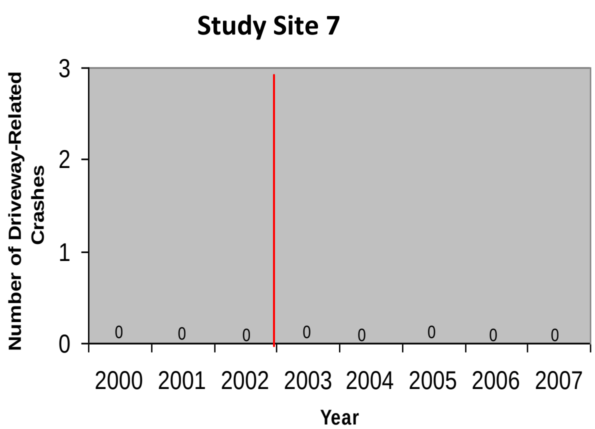
Site 7: BP Gas Station w/convenience market and fast-food restaurants, M-13, Lennon (corner site; before intersection)

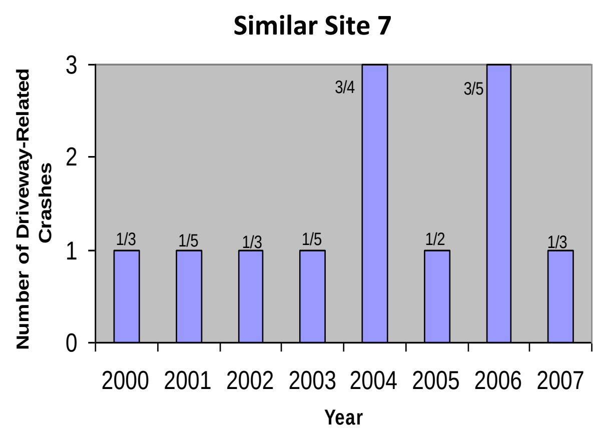
(a) study site

(b) similar site

This site is a mixed-use development consisting of a gas station, convenience market, and two fast food restaurants. The land-use was changed to the gas station in 2004. ADT on M-13 is 4,480, a lower-volume site. This site was located in a somewhat rural area with no major adjacent developments. The gas station was a corner mixed development. The driveway being studied was restricted to a single lane right-in/out-only driveway with a large island channelization. There were few illegal left turns noted during the site visit.

The similar site was a Speedway gas station and convenience store at the corner of Center and Bristol Roads in Burton. The site has contained these land uses since at least 2001 and is full-access. The ADT on the adjacent street was 11,893, appreciably higher than the study site but still under the FHWA figure for being deemed "high volume."





Site	Type of Access	Adjacent Road	Time Span	Total Crashes at the Adjacent Road	Driveway Related Crashes	
					#	%
Study Site 7	RIRO	M-13	Before 2003	4	0	0
			After 2003	1	0	0
Similar Site 7	Full Access	Center Rd	2000-2007	30	12	40

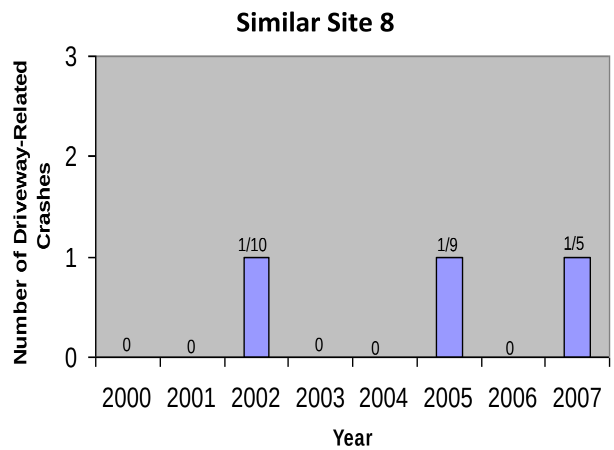
Results of the analysis showed no driveway-related crash in the past seven years at this site. Even in the vicinity of the site, a very low crash frequency was observed before and after the site was changed. By comparison, the similar site had at least one driveway-related crash every year on the Bristol Road. The analysis showed 12 driveway-related crashes in the past eight years. It was also observed that most of the crashes involved the left-out movement from the driveway and some of them involved cross movement from this driveway to a driveway across the street. It appears that the proximity of this driveway to the intersection and the cross-traffic maneuvers from this driveway to the driveway across the street are causing problems at this site.

Overall, while it appears that the crash history at the study site reveals nothing positive (other than restricting access at relatively low volume locations does not degrade the safety), the examination of the unrestricted access at the similar site shows some continuing safety-related problems. Note, however, that the ADT is considerably higher than the study site and is approaching the definition of "high volume."

Site 8: National City Bank and Advance Auto Parts, US-12 (Chicago Road) and Michigan Avenue, Coldwater (corner site; before intersection)

(a) study site (b) similar site

The development at this site consists of a bank and an auto parts store. The information regarding the changes at the site was not found through readily-available sources. However, the bank at this site seemed to be new, as the latest online image available (above) does not show the bank. The driveway on the Chicago Rd is "right-in only" and the ADT is surprisingly high at 17,710 vpd. The similar site is a combination of CITI Financial and a Subway store near the intersection of Davison and Belsay Roads in Burton. The driveway of interest provides unrestricted access to the site and the ADT is 9,648.



Site	Type of Access	Adjacent Road	Total Crashes at the Adjacent Road	Driveway Related Crashes	
				#	%
Study Site 8	Right-in only	US-12	43	0	0
Similar Site 8	Full Access	Belsay Rd	45	3	6.6

There was no clear evidence that there were any crashes related to the site driveway although the time periods examined may not have actually included the site in its new configuration. While the ADT is high, the turning volumes from the site over time were probably quite low as the prior use (see photo) was not very intense. However, the full-access drive at the similar Belsay Road site experienced some crashes.

Site 9: Family Video, M-66 (Capital Avenue) and Emmett Street, Battle Creek (corner site; before intersection)

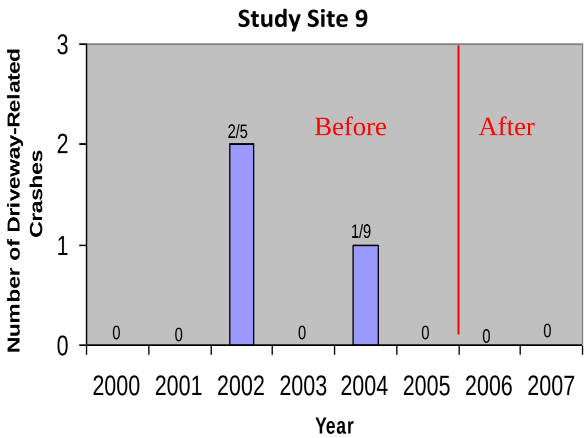
(a) study site (b) similar site

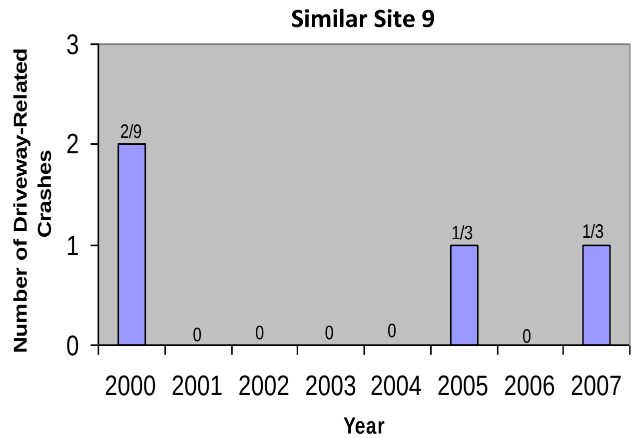
This site is a video rental store and located at the SE quadrant of M-66 (Capital Avenue) and Emmett Street in Battle Creek. Examination of hard copies of crash reports (forms UD-10) for this site revealed that the development was a bank until 2006 and then changed to Family Video. The ADT on M-66 is 14,800 (while not exceeding the definition for a high-volume road, it's probably "close enough). It is not totally clear when the driveway was changed from full-access to its current "right-in-only" status—it was probably at least in 2006 and maybe earlier than that (see discussion below). Note that the access control at this site is somewhat different from the others in that a right-turn-out is not permitted. Moreover, the channelization seems to be more emphatic—e.g., (illegal) left turns appear to be much harder to make than at other sites.

The similar site is the same type of video store on Center Road near Atherton Road in Burton. The ADT on Center is 15,083 and the driveway provides full access.

Over the study period (see figure and table on the next page), the crashes that occurred at the study site involved both left-in and right-in movements. As some crashes involved left-in movements (prior to 2006) it is not clear whether the driveway was channelized at that time (and the turns were prohibited) or the driveway was full access. In any event, no driveway-related crashes were reported at this driveway after 2004. So, it would appear that the turn restriction has been successful at the study site.

The crash history at the similar site (with full access) shows occasional driveway-related crashes throughout the examination period, including at least two which involved left-turning vehicles.





Site	Type of Access	Adjacent Road	Time Span	Total Crashes at the Adjacent Road	Driveway Related Crashes #	Driveway Related Crashes %
Study Site 9	Right-in only	M-66	Before 2006	37	3	8.1
			After 2006	2	0	0
Similar Site 9	Full Access	Center Rd	2000-2007	58	4	6.9

Discussion and Conclusions

As it turns out, there was more variation in the types of sites than had been expected—sites varied by location relative to the intersection, land use for the development, the type of access control employed, the length of before and after periods, and ADT, among other things . Moreover, it was quite difficult to find what might be considered “pure” control sites for comparison purposes. Thus, the analysis of the safety-related (crash) impacts of restricting access control is qualitative rather than statistical. Those points notwithstanding, the analysis does lead to some reasonable conclusions. These will be used with the findings from the simulation studies to develop guidelines for controlling access.

First, a summary table is presented which covers the crash analysis for all nine sites. Then a list of conclusions and discussion is provided.

Table 3. Summary of crash analysis results for all study and similar sites

volume category	site	ADT	type of control	corner clearance	relation to corner	driveway-related crash history	
						before	after
corner sites							
high[1]	site 1	33,200	RIRO	209	before	3	0
	similar site 1	19,857	full	170	before	9[2]	
	site 9	14,800	RIRO	224	before	3	0
	similar site 9	15,083	full	150	before	4[2]	
	site 8	17,170	RI-only	252	before	0	0
	similar site 8	9,648[3]	full	275	before	3[2]	
	site 4	18,400	RIRO	224	after	5	2
	similar site 4	20,800	full	150	after	5[2]	
low-medium	site 7	4,480	RIRO	229	before	0	0
	similar sIte7	11,893	full	100	before	12[2]	
	site 3	11,210	RIRO	186	after	1	0
	similar site 3	5,390	full	need #	after	0	
mid-block sites							
high	site 2	28,100	RIRO	N/A	N/A	0	0
	similar site 2	17,100	full	N/A	N/A	3[2]	
	site 5	27,200	RIRO	182[4]	N/A	0	1
	similar site 5	27,200	full	185[4]	N/A	3[5]	
	site 6	38,140	RIRO + LI	N/A	N/A	0	0
	similar site 6	38,140	RIRO	N/A	N/A	1	

[1] high volume: ADT>15000vpd
[2] spread over entire period
[3] does not meet high-volume criterion—included because similar to study site on other grounds
[4] unsignalized access road/development driveway
[5] distribution not even over period—more crashes earlier but no more than 1/year

- ✓ At the high-volume (ADT>15,000 vpd) corner sites there appears to be a reduction of driveway-related crashes when access control is changed from full access to right-in/right-out. For the similar sites, there were fairly constant numbers of annual crashes. However, the crash frequencies for the sites considered was not high to start with. At best, it would appear that the crash reduction would be one crash/year or less. This finding is reasonably consistent with the literature and the crash reduction factors shown in table 2.

- ✓ It is not clear how corner clearances or other geometric differences among the sites impacted the crash frequencies.

- ✓ Significant changes in crash severity were really not apparent.

- ✓ For the low-medium volume corner sites, there did not appear to be much of a problem with crashes during the before or after periods.

- ✓ The crash frequencies at the mid-block sites did not change appreciably since there was little evidence of a problem in the before period. It should be noted, however, that the sites reviewed all experienced relatively low turning volumes—i.e., driveways serving major malls were not in the mix.
- ✓ During the examination of several of the high-volume similar (corner) sites, it was observed that there was significantly more involvement of outbound left-turning vehicles than inbound lefts in crashes and that right-turning vehicles were seldom, if ever, involved.
- ✓ The turning restrictions associated with access control were observed to be violated in many instances. The existing channelization and/or signing (both of which vary considerably) is not completely effective in preventing the prohibited turning movements.

To summarize the findings of the safety/crash analysis: based on an analysis of a variety of existing sites where access control has been changed, there is some evidence that access control will result in lower crash frequencies in some instances, but the crash reduction when modest turning volumes are involved is relatively low.

OPERATIONAL IMPACTS

While the safety review indicated that there were some modest savings due to crash reduction for higher-volume corner locations on higher-volume streets, one of the remaining questions is whether there are travel delay impacts which are consistent: Do vehicle delays that are associated with different access control scenarios "warrant" restricting access control?

For this part of the investigation, the traffic simulation model VISSIM was used to simulate operations at the various sites, and then conditions (e.g., street volume, turning volume, corner clearance) were varied to show when operations became untenable. Synchro (a Highway Capacity Manual [HCM]-based software used to evaluate intersection operation) was also used to assess existing conditions at each site and to optimize signal timing to be used in the simulation model.

Basic Simulation Model and Assumptions.

The basic modeling process is described below.

- Because of the variance in the number and use of lanes at the various sites, a total of eight VISSIM models were developed, six were for corner and two for mid-block sites. The corner sites were further grouped into two categories: four where the driveway is before the intersection and two where the driveway is after.

- In addition to the geometric layout and location of the driveway which were explicit in each model, four other factors were considered: corner clearance (CC), mainline volume (MV), driveway volume (DV), and left-turn-in and -out volume (LT). CC was defined as the distance in feet from the inside edge of the intersection to the (near) inside edge of the driveway. MV was defined as the volume in vehicles per hour (vph) on the main roadway adjacent to the study driveway. DV was defined as the driveway volume in vph entering and exiting the facility exclusive of the MV. LT was defined as the left turn in and out volume in vph. Even though LT is a driveway volume, it was considered as a separate variable.

- Each of the variables was varied over a specified range and separate simulation runs were made for each combination for different kinds of access control. The ranges were defined to account for logical ranges for the types of development and roadway conditions encountered in the field. Traffic volumes were varied so that traffic operations would eventually break down. The ranges for the variables are: CC—150, 250, and 350 feet; MV—250, 500, 1000, 1500, and 2000 vph; DV—25 and 150 vph; and LT—10 and 50 vph.

- The five access control scenarios were: (1) no driveway; (2) RT-in only; (3) RT-in/out only; (4) RT-in/out + LT-in; and (5) full access.

- It was assumed that the driveway trips were passer-by trips, e.g., if they were traveling eastbound prior to turning into the development, they traveled eastbound upon exiting (right-turn in, right-turn out). Since there was no LT-out for RT-in/out + LT-in only driveway, the LT-out traffic in that case was assumed to leave the facility through a RT-out exit and was added to the mainstream traffic at the intersection.

- After the basic model was specified, the models were calibrated to simulate the actual conditions as observed in the field. A separate VISSIM model was built for each site for the existing conditions of geometry, mainline and driveway volumes, and signal timings and phases. Since the major measures of effectiveness (MOEs) measured in the field were travel time and queue length, the average travel time and queue length outputs from the simulations were compared with the field data. The VISSIM input factors (e.g., vehicle performance—acceleration/deceleration rates, driver characteristics—percentages of different drivers, and lane-change behavior—aggressive or passive) were initially used as default values. The results obtained for the travel times and queue lengths using these default values were close to field observations. The VISSIM outputs were also checked against Synchro outputs (e.g., average delay and maximum queue lengths). The results obtained for this comparison were close, and thus the VISSIM models were considered to be reasonable to use for the project.

- When mainline volumes (MV) were allowed to vary, it was necessary to make an assumption about what would logically occur on the other approaches to the intersection (this will impact overall intersection delay). Three cases were reviewed for the first model: Case 1—only the MV on the subject approach changes; Case 2—MV volume in both directions changes (proportionately) and Case 3—the MV for all approaches changes. After considerable discussion and examination of the output, Case 2 was selected as the most appropriate and logical case. Thus, all models were "exercised" using this assumption.

- In an actual situation where turns in to/out of a development are prohibited, traffic might make a U-turn after the intersection or somehow turn around and come back, and thus impact intersection delay. Such potential movements were ignored in the work presented here—the effects are expected to be minimal on the MOEs that were used.

- Synchro was used to optimize signal timings for each increment of MV. These timings were then used in the VISSIM models.

Operational Analysis Using VISSIM.

Once the basic modeling construct was developed, the various models were adopted and run for the various combinations of the key factors. For each model, the process for obtaining and displaying the results from the VISSIM output is described below.

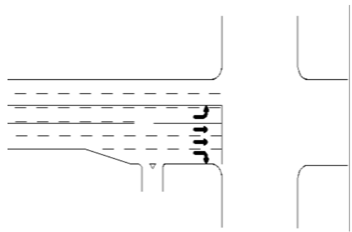
- The primary criterion for prohibiting LT-in and -out traffic was the average delay (sec/veh) for these movements. Average delay equivalent to level of service (LOS) C or better was considered to be acceptable. The LOS criteria for unsignalized intersections provided by Highway Capacity Manual were used to define the threshold values. Graphs for average total delay and 50^{th} percentile queue lengths were plotted to check the impact of MV and DV on the mainline traffic. However, since the motorists using the driveway had to stop for gaps in the mainline volume, the average delay of mainline volume was not the principal criterion. On the average delay graphs, the cutoff lines are shown for LOS C and D as red and blue lines, respectively. The line for LOS C indicates that if the average delay was below this line, the LOS was C or better. Similarly, an outcome above the blue line showed that the average delay was worse than LOS D.

- The 50^{th} percentile queue lengths were used to show the MV, DV, and LT combination for which the queue length will exceed the CC half of the time during the analysis period.

- A summary of results for each model was prepared in a tabular format to show outcomes for the various combinations of CC, MV, DV, and LT (see the presentation for model 1 below for illustrations). These tables were prepared using the detailed graphs for average delay and 50% queue length and the criteria for left-turn restriction. These tables are helpful in understanding the trends and provide an overview of the impacts of ranges of different variables. Different symbols are used to indicate the combinations where left turns in and out are recommended to be restricted. The locations on graphs where left turns were recommended as "prohibited" are indicated by "●," and where left turns "may be allowed" by "○." Those points where the left-turn prohibition recommendations were not clear due to other factors (beyond what was defined in the analysis) are shown by "⦿." The prohibitions for LT-in as well as LT-out are shown together in the summary table.

Results for Model (site) 1 *(lane configuration = 1 LT, 2 TH, and 1 RT—study site 1)*

Site 1 is a fairly typical arterial roadway type often found in suburban areas, a basic 5-lane section which widens at the intersection to accommodate a right-turn lane.



The observed split by turning movement is:

Left	*Through*	*Right*
9.4%	*77.6%*	*13.0%*

In the following paragraphs, selected graphs illustrating various simulation results are presented. These include average total delay (sec/veh) for the mainline traffic and the 50th percentile queue length (ft).

Average Delay (sec/veh) for Mainline Traffic.

The total average delay for the approach of interest was plotted against different increments of MV, CC, and minimum and maximum values of DV and LT. In the following, the average delay graphs for CC = 150ft are shown with two different left-turning volumes (10 and 50 vph). (The average delay graphs for CC of 250 and 350ft showed similar results, thus, not shown).

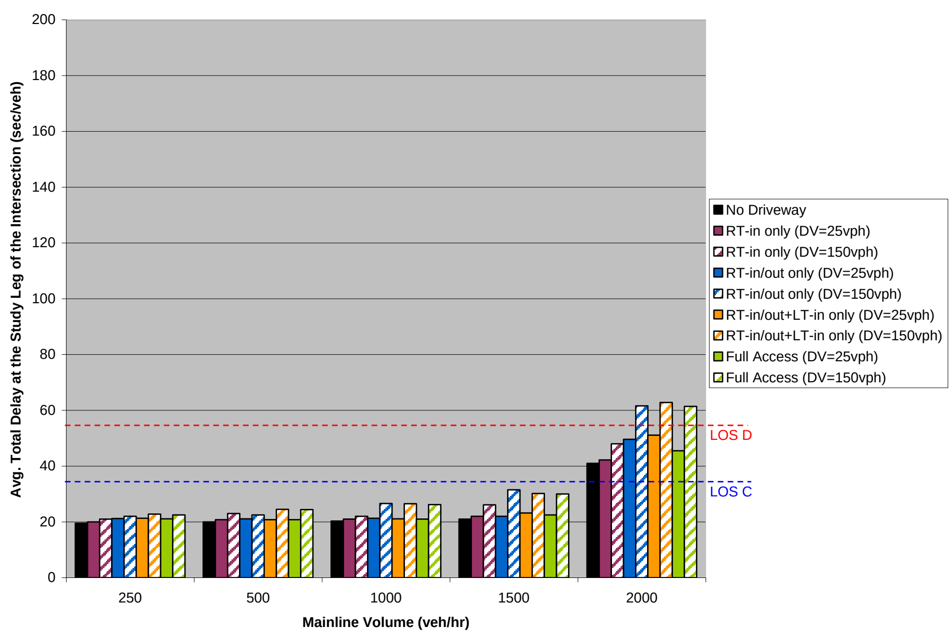


Figure 7. Comparison of Average Total Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft and LT-in ***Vol=10vph***

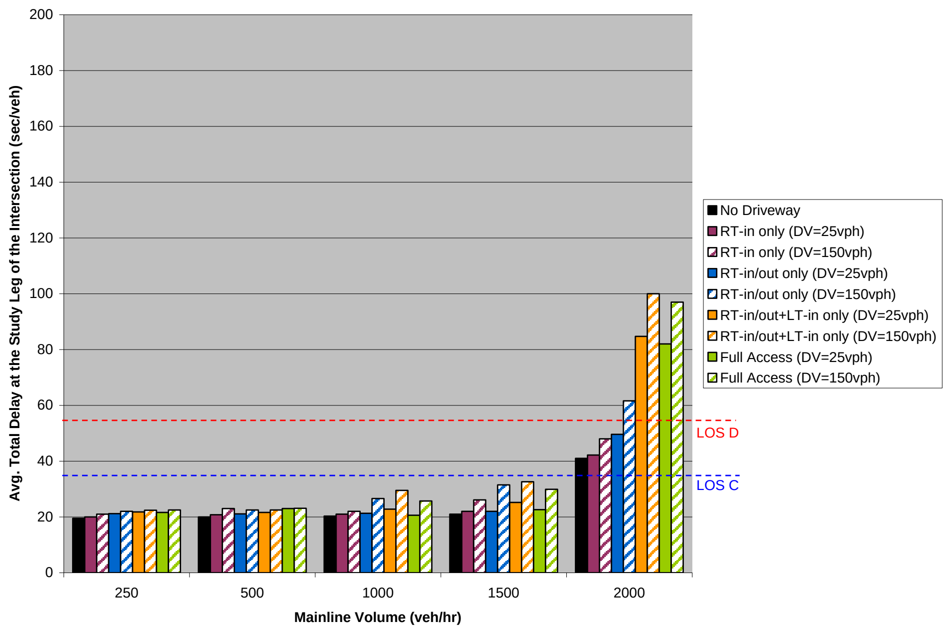


Figure 8. Comparison of Average Total Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

From the graphs, it can be seen that the average delay for the mainline traffic became worse than LOS C as the MV approached 2000vph. However, the differences among the various turning restriction scenarios (different column heights) are more apparent with the higher turning volumes. In the first figure (LT-in=10vph), all of the vertical bars are about the same height whereas in the second (LT-in =50vph) the scenarios that restrict left turns in and/or out perform better than those that do not. Since driveway traffic and delay are dependent on the mainline traffic, they are used for developing the access prohibition criteria.

<u>Average Delay (sec/veh) for Driveway Traffic (vph)</u>.

The average delay for the driveway-related traffic was separated out and also compared to threshold LOS criteria (for unsignalized intersections from the HCM). According to this criterion, LOS C corresponds to an average delay of ~15-25 seconds, and LOS D to ~25-35 seconds. The average delays were plotted separately for LT-in and LT-out driveway volumes against different increments of MV, CC, and minimum and maximum values of DV and LT. In the following figures, the average delay graphs for left turns in and out traffic are shown for CC of 150ft with LT volumes of 10 and 50 vph. Similar sets of graphs were also obtained for CC = 250 and 350ft (shown in appendix 5) and used in the development of LT-prohibition recommendations.

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

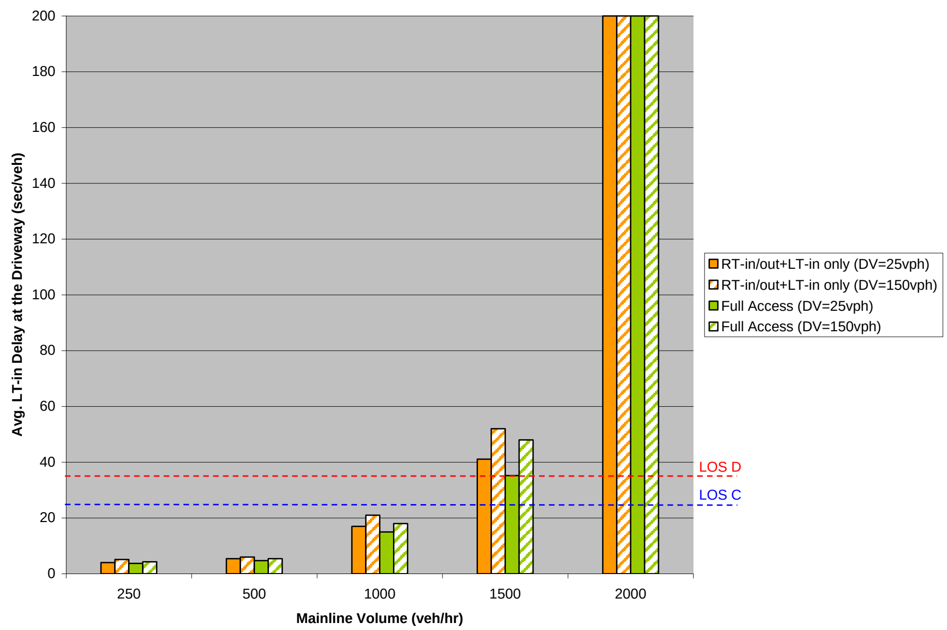


Figure 9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

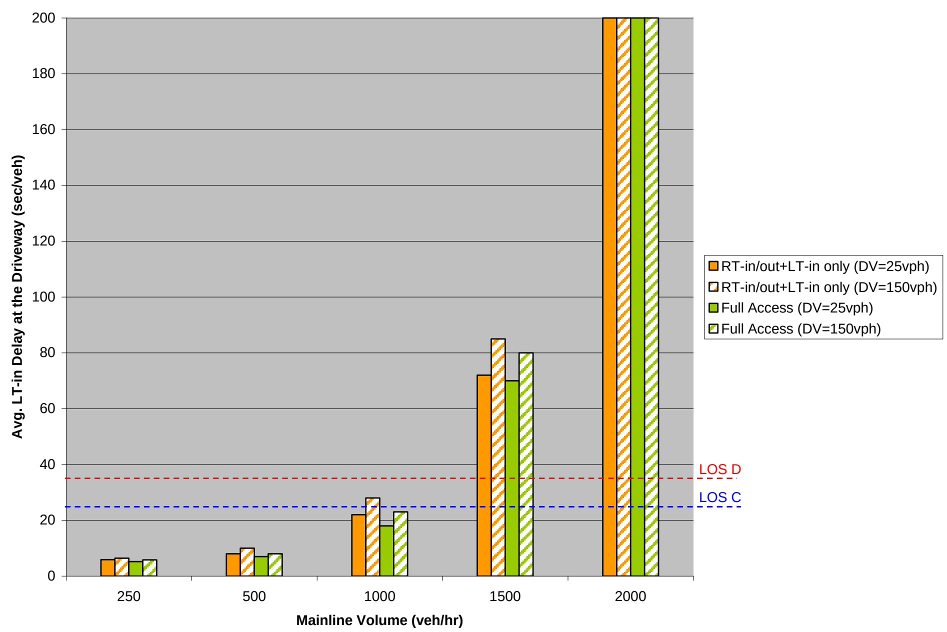


Figure 10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

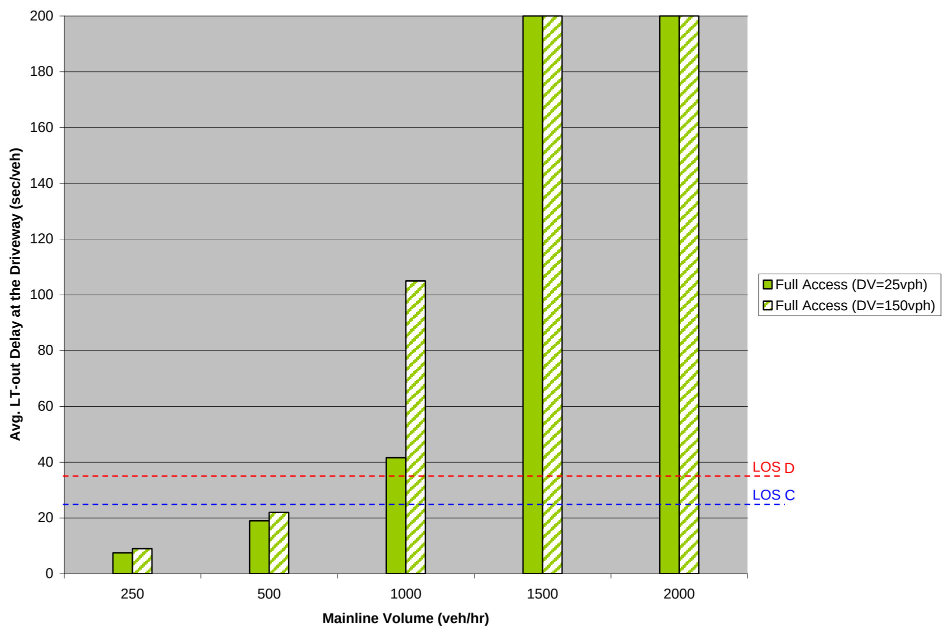


Figure 11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

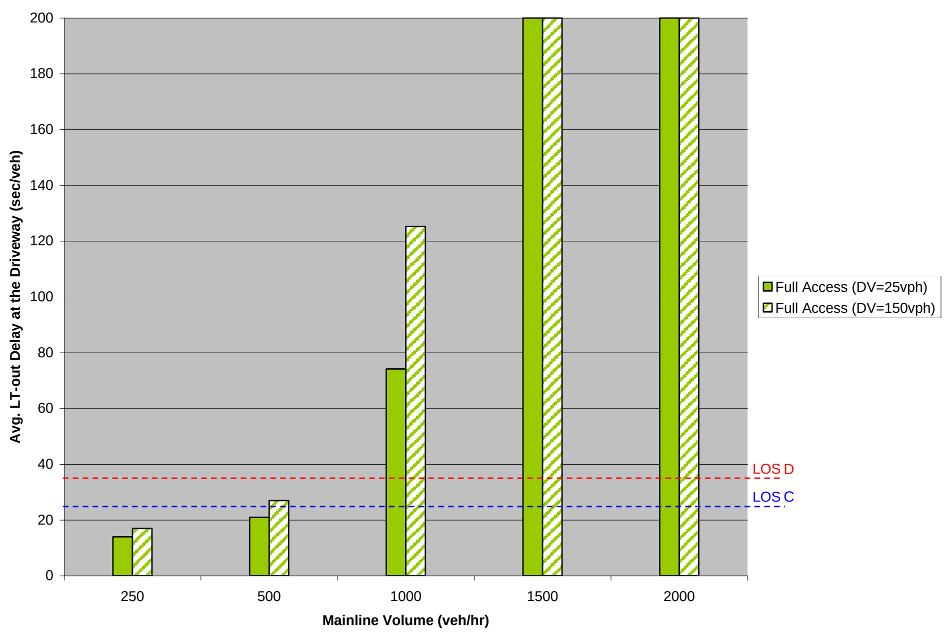


Figure 12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

The graphs above (and those in the appendix) show that when the driveway delays are broken out and considered separately, there are delay problems with some scenarios and they occur at mid-range to higher values of MV. It can also be observed that the left-turn-out delays were generally higher than left- turn-in delays. This can be explained by the fact that left-turn-out vehicles required a gap in both the near-side and far-side traffic (i.e., traffic from both directions). Left-turn-in vehicles, however, only needed gaps in traffic from one (mainline) direction.

50th Percentile Queue Length (ft) vs. Mainline Volume (vph)

The next two figures are graphs that show the 50th percentile queue lengths, again for LT-in volumes of 10 and 50 vph. Different threshold values of CC are also shown (since the difference in the queue lengths were not much, the corner clearance "thresholds" are all shown on the same graph for simplicity). Not surprisingly, it is observed that problems arise at higher mainline volumes. That is, queue lengths become problematic (they block the driveway—graphically, the plotted queue lengths are greater than the threshold values of CC) at higher values for MV and DV. The critical MV is estimated, in these cases, to be about 1600vph with a DV of about 100vph or higher. It may be noted that for this model, the average queue lengths were relatively shorter up to MV=1500vph due to the queues clearing during the green phase of the signal.

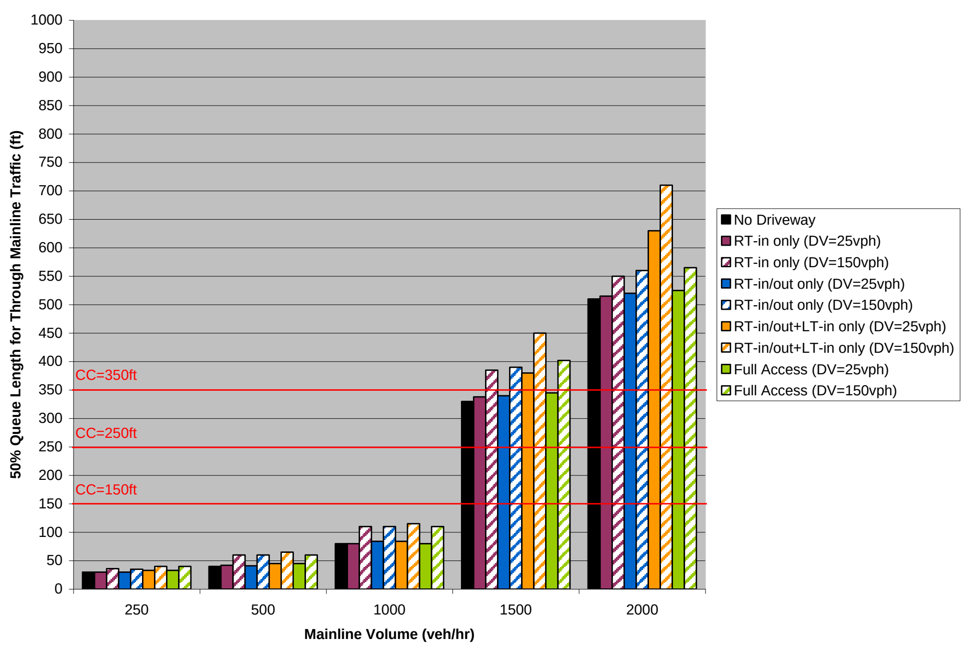


Figure 13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

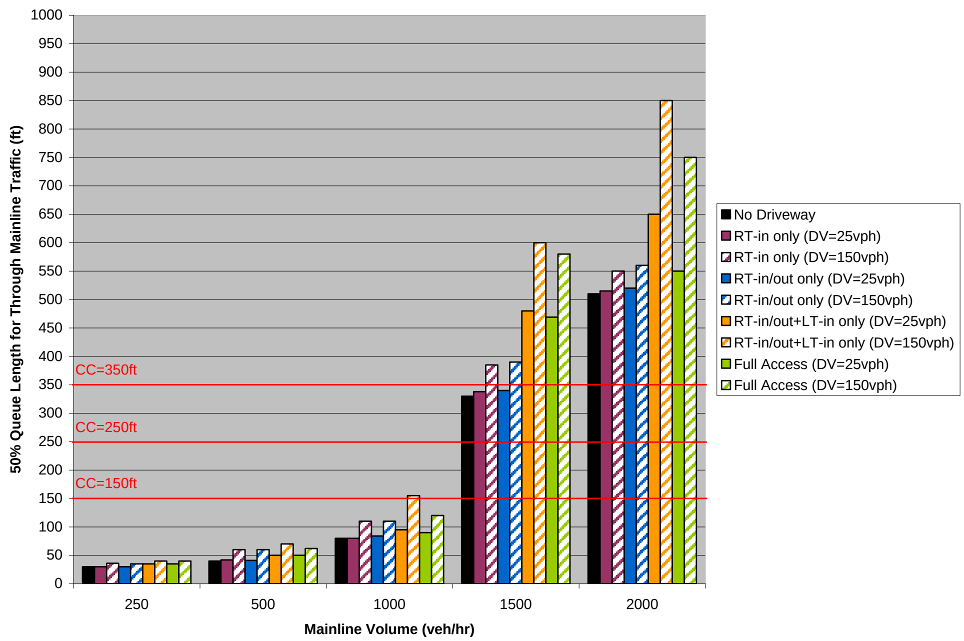


Figure 14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Summary and Conclusions Based on Model 1 (Site 1)

The operational impacts of different values of (corner clearance) CC and driveway access types were evaluated using Model 1 and varying MV (mainline volume), DV (driveway volume), and LT (left-turning volume). (Reiterating, model 1 represents the case of a corner site before a signalized intersection, where the lane configuration of the main road is one left-turn lane, two through lanes, and one right-turn lane.) The figures (above) showing the various delays and 50% queue lengths for these different values and under different turning scenarios were reviewed, and the results are summarized below. The results are then used to derive "guidelines" for when left turns should be prohibited. The summary and conclusions:

- An increase in MV has relatively more impact on the average delay and queue length of the mainline traffic than increases in DV.
- The negative impact due to increases in MV, DV, and LT was greater when CC was less than 150ft as opposed to 250ft or more.
- When the MV approached 2000vph, the driveway was blocked for all values of CC and all combinations of DV and LT.
- The impact of minimum and maximum DV on the average delay was more significant as MV approached 1500vph.

- In general, the average delay for RT-in/out+LT-in-only was greater as compared to a full-access driveway when MV reached 1500vph or higher. The possible reason for this higher delay for no left-turn-out is the assumption that the driveway trips are passer-by trips. Therefore, the left-turn-in traffic left the facility using the right-out exit and thus is added to the mainline traffic on the intersection approach being studied. However, for the full access case, this traffic is not added at the adjacent intersection; hence producing somewhat less average delay.

- In general, all type of driveways performed similarly with respect to average delay when the MV was equal or less than 1500vph—i.e., the average total delay of the mainline traffic did not vary very much, regardless of the driveway type. However, RT-in/out+LT-in only and full access driveway types produced relatively larger delays due to the LT-in and out traffic.

- The delay for LT-out traffic was more as compared to LT-in. The possible reason could be the extra time that LT-out vehicles have to experience in order to obtain gap in the near and far mainline traffic streams.

- The queue lengths for mainline traffic became greater than the CC value(s) for about 50% of the time, when the MV approached 1300vph. The queues were greater when the LT volume was 50vph (vs. 10vph). It was observed that for a given value of CC, the driveway left turns became problematic for higher values of DV (closer to 150 and higher).

Recommended Access Control Guidelines Based on Model 1 (Site 1) Results

Based on the foregoing, the following access control guidelines are tentatively suggested for approach geometry consisting of one left-turn-only lane, two through lanes, and one right-turn-only lane. These will be fine-tuned and/or generalized as the results from other models are considered in subsequent sections.

1) When the CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.

2) When 100<CC≤150ft, MV≥1000vph, left turns out should be prohibited for left turn out traffic; and in addition, the left turns in should be prohibited if DV≥150vph and LT≥10vph.

3) When 150<CC≤250ft, left turns in may be allowed as long as MV≤ 1500vph, DV≤ 150vph, and LT≤50vph. Left turns out may be allowed as long as MV≤ 1000vph, DV≤ 150vph, and LT≤50vph.

4) When 250<CC≤350ft, the criteria for allowing left turns in and out are the same as 3) above.

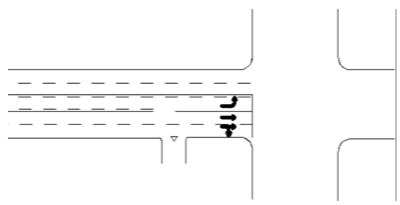
5) When CC>350ft, left turns in may be allowed as long as MV≤ 1500vph, DV≤ 150vph, and LT≤50vph. Left turns out may be allowed as long as MV≤ 1500vph, DV≤150vph and LT≤50vph.

6) Caution should be exercised for allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

It should be noted that even though these are “recommendations,” they are not strict rules and could be mitigated by unique conditions at a site. Before applying these recommendations, a site investigation including safety considerations should be done. These recommendations are summarized in the chart on the following page. The chart is color-coded to show when left turns in and out of the development should definitely be prohibited (red), when left turns in and out should be considered separately or there are other issues to be considered (orange), and when they can be permitted (green). In the next section, the second model (for a different geometric condition) is considered.

Results for Model 2 *(lane configuration = 1 LT, 1 TH-only, 1 TH and RT—study sites 5 and 8)*

Sites 5 and 8 are similar to site 1 except there is no exclusive RT lane. This site is also a typical arterial roadway often found in suburban areas, a basic 5-lane section.



The observed split by turning movement is:

Left	*Through*	*Right*
8.0%	*81.0%*	*11.0%*

In this and succeeding sections, only narrative is presented although graphs similar to those for model (site) 1 were also developed and analyzed—these are shown in appendix 6 but not explicitly referenced.

<u>**Summary and Conclusions Based on Model 2 (Sites 5 and 8)**</u>

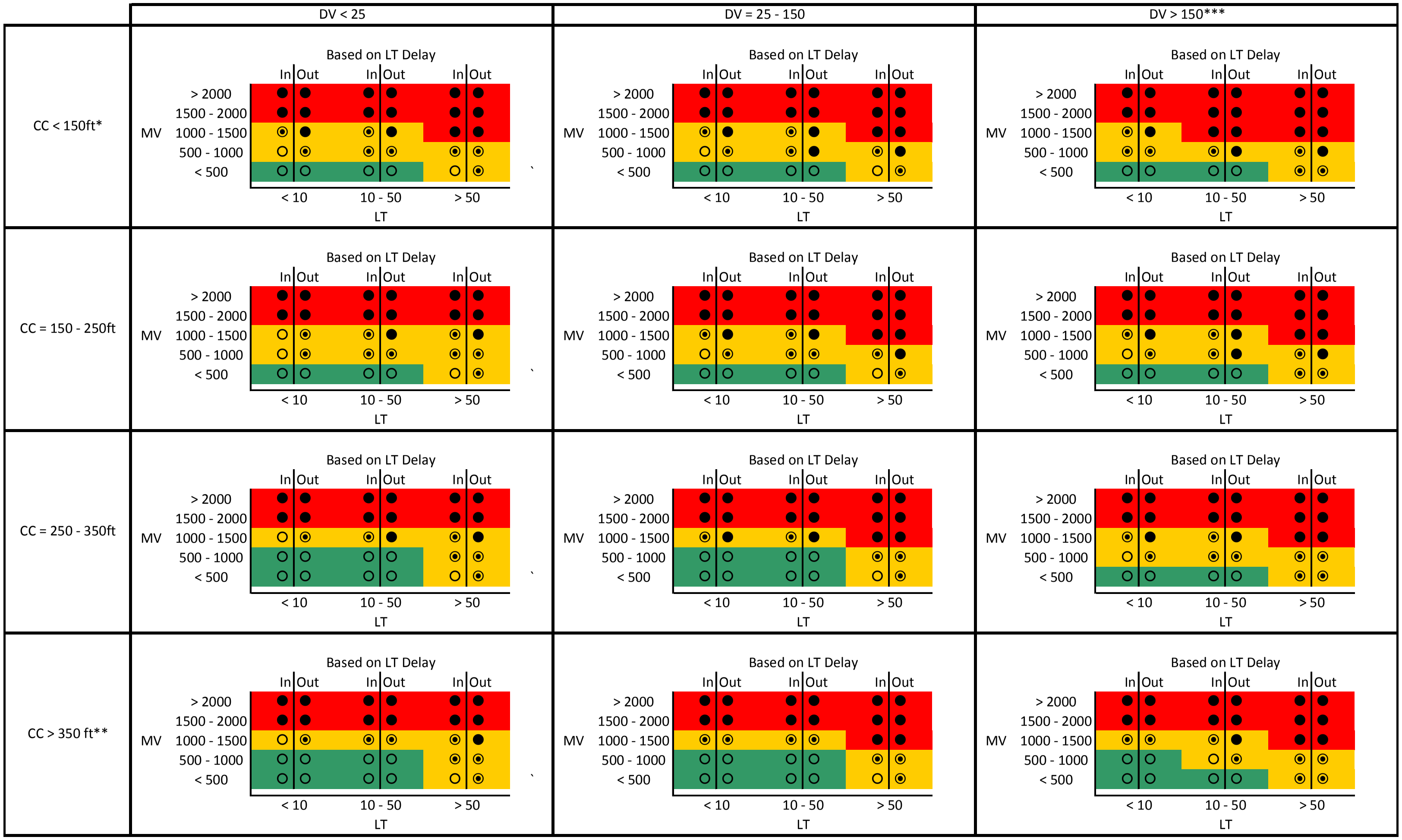
Based on the combined results for average driveway-related delays and % queue lengths, the summary and conclusions are:

- Increase in MV has relatively more impact on the average delay and queue length of the mainline traffic than increases in DV.
- The negative impact due to increase in MV, DV and LT was greater when CC < 150ft as opposed to 250ft or higher
- The left-turn-out traffic was more negatively affected by increases in MV, DV, and LT than the left-turn-in traffic.
- When the MV approached 2000vph, the driveway was blocked for all values of CC and all combinations of DV and LT.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 1

Type: Corner Site "Before" Intersection
Number of Lanes: 1 Left, 2 Through, 1 Right
Percentage Split of Mainline Volume at the Study Leg: Left=9.4%, Through=77.6%, Right=13.0%



LEGEND:

- CC = Corner Clearance (ft)
- DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
- MV = Mainline Volume (vph)
- LT = Left Turns In and Out (vph) => Not part of DV
- ● = Prohibit LT
- ⊙ = May Prohibit LT for Higher Values of DV, LT, MV
- ○ = May Allow LT
- (red) = Left Turns In/Out as a "Pair" Should be Prohibited
- (yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
- (green) = Left Turns In/Out as a "Pair" Maybe Allowed

NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.

** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.

*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 15. Summary of Left Turn Restriction Recommendations for Model 1

- From the average delay graphs (similar to Model 1), the average delay for RT-in/out+LT-in-only (in general) was found out to be greater as compared to a full-access driveway when MV ≥ 1500vph.

- In general, all types of driveways performed similarly with respect to average delay when the MV ≤ 1500vph—i.e., the average total delay of the mainline traffic was similar, regardless of the driveway type. However, RT-in/out+LT-in-only and full access driveway types produced relatively larger delays due to the LT-in and -out traffic.

- For this model, it was observed that the queues dissipated much quicker even for higher volumes. The possible reason could be the fact that the traffic was relatively lower on the N-S approaches (i.e., the cross street at the intersection). This resulted in more green time for the E-W traffic (i.e., the study mainline traffic which is proportionally varied). So, even though, the 50th percentile queue lengths provided useful information, they were not used as a principal determinant to prohibit left turns.

Evolving Guidelines Based on Model 2 (Site 5 and 8)

Based on the foregoing, the evolving access guidelines are recommended for a development located at a corner before a signalized intersection where the approach geometry is one left-turn, one through, and one through-right (no exclusive right-turn lane) lanes:

1) When CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.

2) When 100<CC≤150ft, both left turns in and out may be allowed as long as MV≤1000vph, DV≤150vph, and LT≤10vph.

3) When 150<CC≤250ft, left turns in may be allowed as long as MV≤1000vph, DV~150vph (or up to 200vph), and LT≤10vph. Left turns out may be allowed as long as MV≤1000vph, DV≤150vph, and LT≤10vph.

4) When 250<CC≤350ft, left turns in may be allowed as long as MV≤ 1500vph, DV≤150vph, and LT≤10vph. Left turns out may be allowed as long as MV≤1000vph, DV≤150vph, and LT≤50vph.

5) When CC>350ft, left turns in may be allowed as long as MV≤ 1500vph, DV≤150vph, and LT≤50vph. The left-turn-out criteria stay the same as in 4) above.

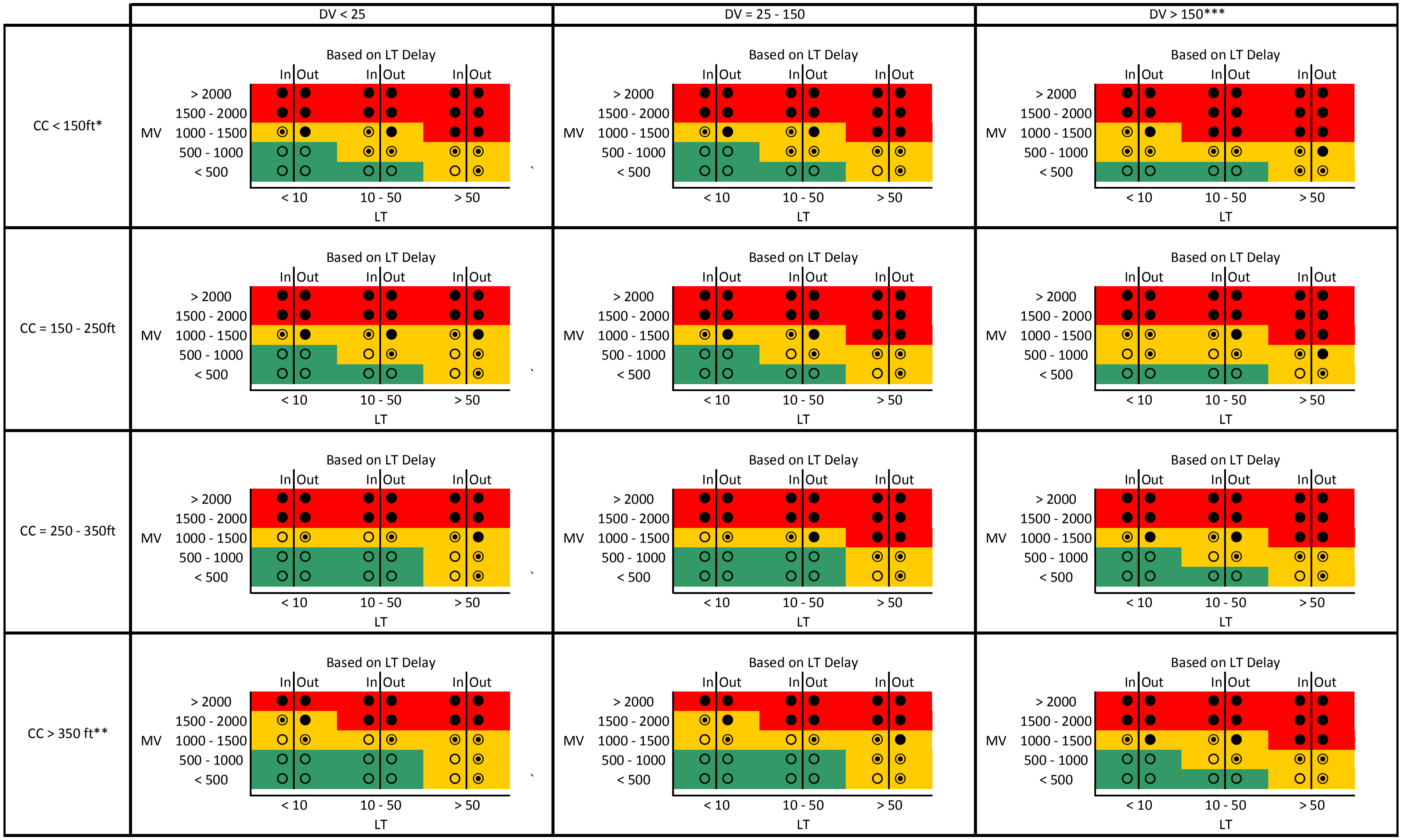
6) Similar to Model 1, caution should be exercised for allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

These recommendations are summarized in the table on the next page.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 2

Type: Corner Site "Before" Intersection
Number of Lanes: 1 Left, 2 Shared Through and Right
Percentage Split of Mainline Volume at the Study Leg: Left=8.0%, Through=81.0%, Right=11.0%



LEGEND:

CC = Corner Clearance (ft)
DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
MV = Mainline Volume (vph)
LT = Left Turns In and Out (vph) => Not part of DV
● = Prohibit LT
⦿ = May Prohibit LT for Higher Values of DV, LT, MV
○ = May Allow LT
(red) = Left Turns In/Out as a "Pair" Should be Prohibited
(yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
(green) = Left Turns In/Out as a "Pair" Maybe Allowed

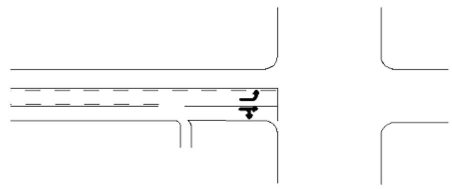
NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.
** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.
*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 16. Summary of Left Turn Restriction Recommendations for Model 2

Results for Model 3 *(lane configuration = 1 LT, 1 TH and RT lanes—study site 9)*

Model 3, based on Site 9, is a basic 3-lane section with a center lane for left turns, but no exclusive right-turn lane. It is a somewhat less typical arterial roadway type as compared to the sites for Models 1 and 2.



The observed split by turning movement is:

Left	*Through*	*Right*
2.5%	*77.7%*	*19.8%*

As was the case with the discussion of Model 2, the summary and conclusions and evolving recommendations are presented here with the supporting figures showing explicit results provided in appendix 7.

Summary and Conclusions Based on Model 3 (Site 9)

Based on the combined results for average driveway-related delays and analysis of queue lengths, the summary and conclusions for this type of situation are:

- Increase in MV has more impact on the average delay and queue length of the mainline traffic than increases in DV. This impact is more significant than for the two previous two situations. This is primarily due to the reduced capacity (less lanes) to accommodate higher mainline volumes.

- The negative impact due to increase in MV, DV, and LT is greater when CC < 150ft as opposed to 250ft or higher.

- The left-turn-out traffic was more negatively affected by increases in MV, DV, and LT as opposed to left-turn-in traffic.

- When the MV approached 1000vph, the driveway was blocked for all values of CC and all combinations of DV and LT.

- RT-in/out+LT-in only and full access driveway types produced relatively larger delays as compared to other driveway types due to LT in and out traffic.

Evolving Guidelines Based on Model 3 (Site 9)

Based on the summary and conclusions just presented and the details in the appendix, the following guidelines are recommended for a development located at a corner before a signalized intersection where the approach geometry is one left-turn and one shared through-right lanes (no exclusive right-turn lane) on the main road approach to the intersection:

1) When CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.

2) When 100<CC≤150ft, left turns in and out may be allowed as long as MV≤ 500vph, DV≤150vph (or approximately less than 200vph), and LT≤10vph.

3) When 150<CC≤250ft, left turns in may be allowed as long as MV<500vph, DV≤150vph (or slightly greater—up to approximately 200vph), and LT≤50vph. The criteria for the left turn out stay the same as in 2) above.

4) When 250<CC≤350ft, the criteria for both left turns in and out stay the same.

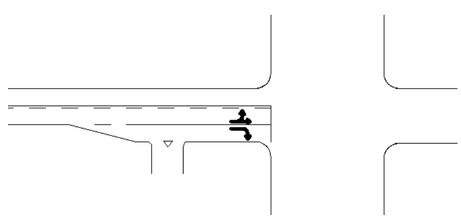
5) When CC>350ft, the criteria for left turns in and out stay the same, however, the criteria may be relaxed for MV up to 700vph.

6) Caution must be exercised for allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

These recommendations are summarized in the following chart.

Results for Model 4 *(lane configuration = 1 Shared LT- TH and 1 RT lanes—study site 7)*

This site is not a typical arterial roadway configuration. It is sometimes found in low traffic suburban areas, a basic 2-lane section which widens at the intersection to accommodate a right-turn lane. It should be noted that since there is no median or center turn lane, vehicles wanting to turn left (in to the site) do not have a storage space, as in earlier scenarios.

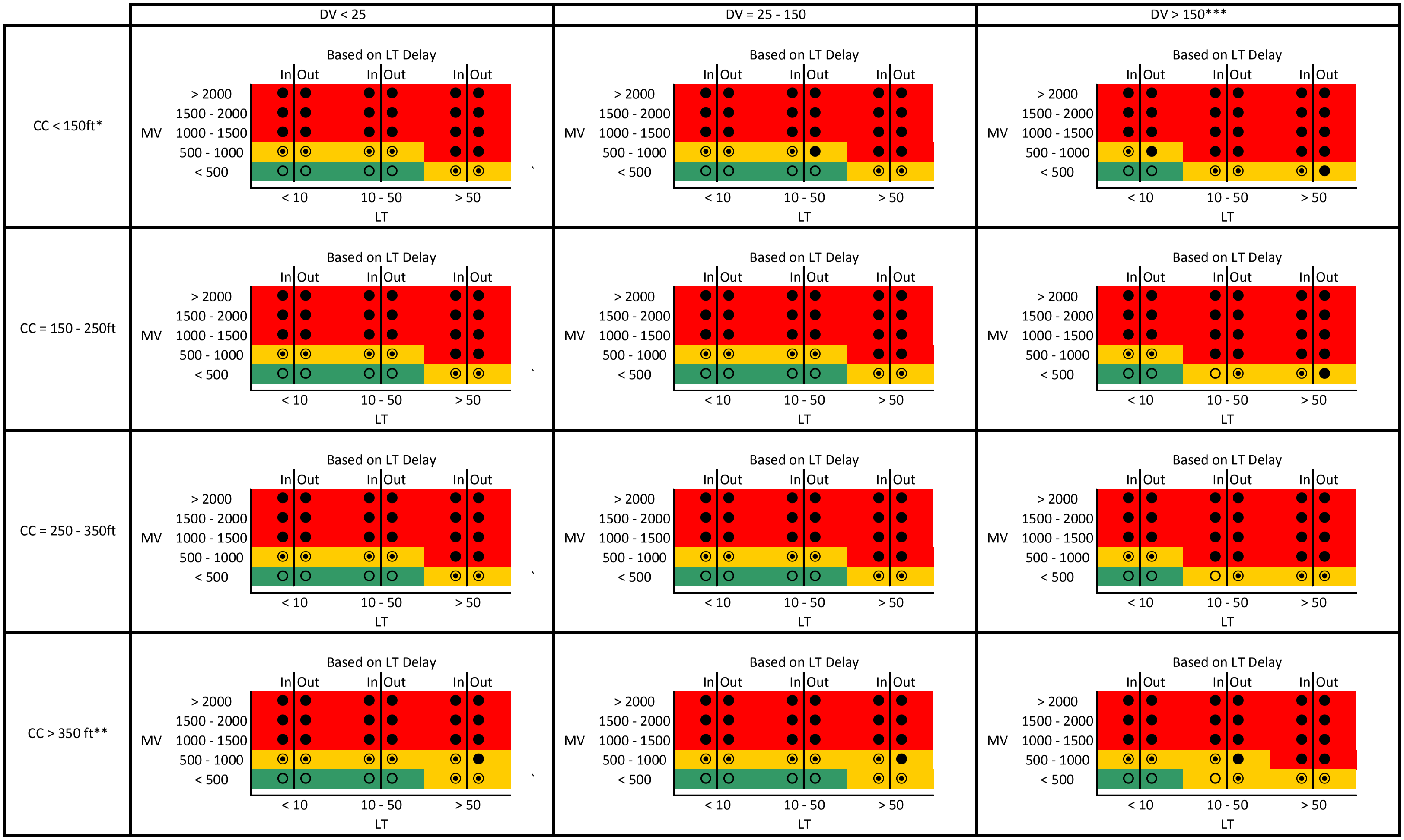


The observed split by turning movement is:

Left	*Through*	*Right*
18.8%	*64.4%*	*18.8%*

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 3 **Type:** Corner Site "Before" Intersection
Number of Lanes: 1 Left, 1 Shared Through and Right
Percentage Split of Mainline Volume at the Study Leg: Left=2.5%, Through=77.7%, Right=19.8%



LEGEND:

CC = Corner Clearance (ft)
DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
MV = Mainline Volume (vph)
LT = Left Turns In and Out (vph) => Not part of DV
● = Prohibit LT
⦿ = May Prohibit LT for Higher Values of DV, LT, MV
○ = May Allow LT
(red) = Left Turns In/Out as a "Pair" Should be Prohibited
(yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
(green) = Left Turns In/Out as a "Pair" Maybe Allowed

NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.
** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.
*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure x. Summary of Left Turn Restriction Recommendations for Model 3

In the following paragraphs, a summary and conclusions based on the simulation results are presented—detailed results are in appendix 8.

Summary and Conclusions Based on Model 4 (Site 7)

Based on the results for average driveway related delays and 50% queue lengths, the summary and conclusions are:

- Increase in MV has more impact on the average delay and queue length of the mainline traffic than increases in DV. This increase is greater than for Models 1 and 2, and closer to Model 3—this is due to the 2-lane section.
- The negative impacts due to an increase in MV, DV, and LT were greater when CC < 150ft as opposed to 250ft or higher.
- The left-turn-out traffic was more negatively affected by increases in MV, DV, and LT than was left-turn-in traffic.
- When the MV approached 1000vph, the driveway was blocked for all values of CC and all combinations of DV and LT.
- RT-in/out+LT-in only and full access driveway types produced relatively larger delays as compared to other driveway types due to LT in and out traffic.

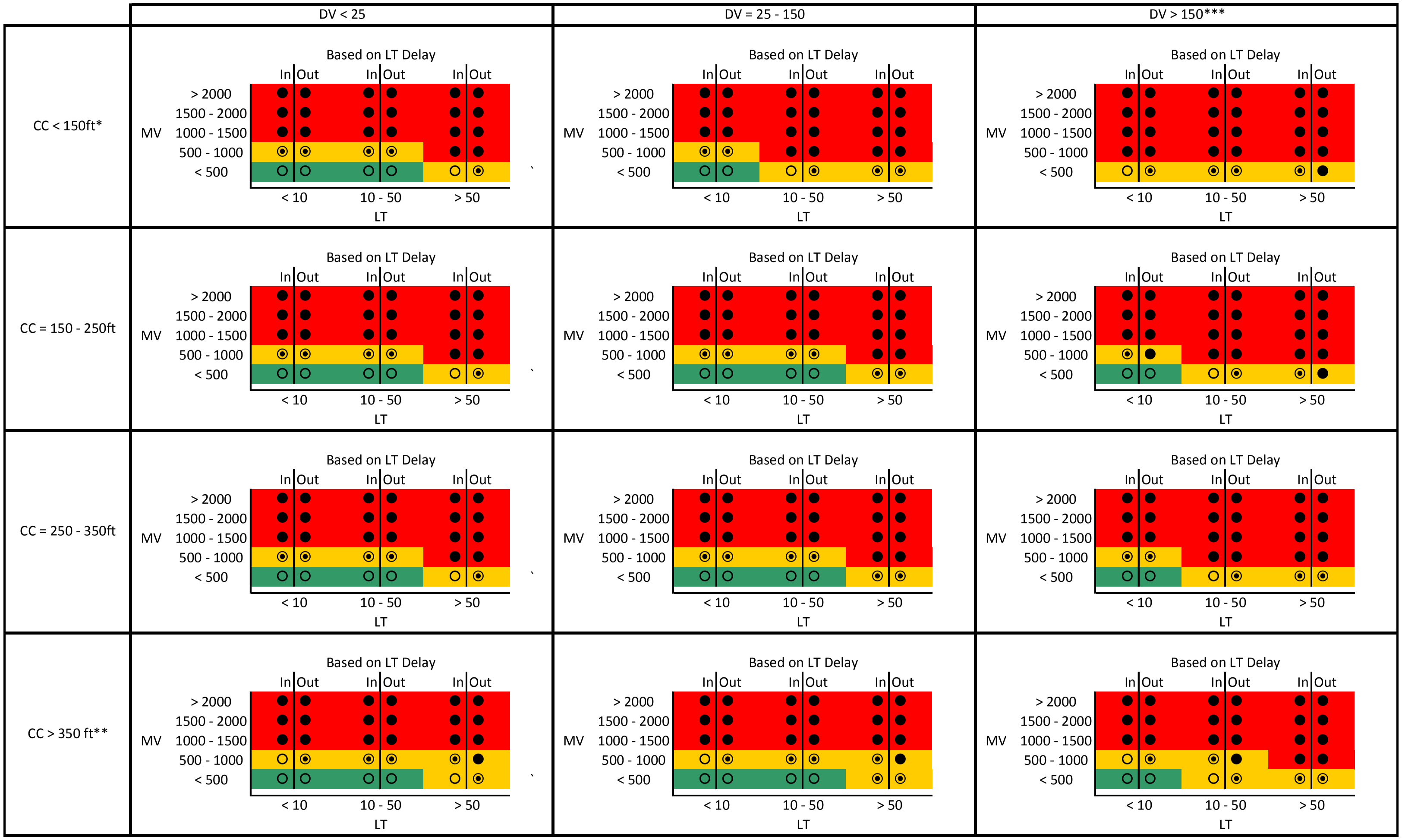
Evolving Guidelines Based on Model 4 (Site 7)

Based on the foregoing, the following access guidelines are recommended for a development located at a corner before a signalized intersection where the approach geometry is one left-turn/through lane and and one right-turn lane (and summarized in the following chart):

1) When CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.
2) When 100<CC≤150ft, left turns in may be allowed as long as MV≤ 500vph, DV≤150vph (or approximately less than 200vph), and LT≤10vph. Left turns out may be allowed as long as MV≤ 500vph, DV≤150vph, and LT≤10vph.
3) When 150<CC≤250ft, the criteria for left turns in stay the same as above. The criteria for left turns out also become the same as for left turns in.
4) When 250<CC≤350ft, the criteria stay the same as above
5) When CC>350ft, left turns in may be allowed as long as MV≤1000vph, DV≤200vph, and LT≤10vph. The criteria for left turns stay the same as previous.
6) Caution must be exercised for allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 4 **Type:** Corner Site "Before" Intersection
Number of Lanes: 1 Shared Left and Through, 1 Right
Percentage Split of Mainline Volume at the Study Leg: Left=18.8%, Through=62.4%, Right=18.8%



LEGEND:

- CC = Corner Clearance (ft)
- DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
- MV = Mainline Volume (vph)
- LT = Left Turns In and Out (vph) => Not part of DV
- ● = Prohibit LT
- ⦿ = May Prohibit LT for Higher Values of DV, LT, MV
- ○ = May Allow LT
- (red) = Left Turns In/Out as a "Pair" Should be Prohibited
- (yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
- (green) = Left Turns In/Out as a "Pair" Maybe Allowed

NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.

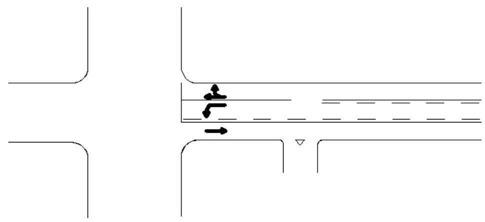
** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.

*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 18. Summary of Left Turn Restriction Recommendations for Model 4

Results for Model 5 *(lane configuration= (near side of adjacent road) 1 TH lane; (far side) 1 LT and 1 shared TH and 1 RT lanes —study site 3)*

Model 5 (site 3) is similar to Model 3 (site 9) in the sense that the geometry of the lanes is similar. However, this site is located AFTER the intersection rather than before it and, so, represents a departure from the sites discussed thus far.



The observed split by turning movement (for traffic flowing to the left in the drawing above) at the intersection is:

Left	*Through*	*Right*
4.1%	*65.1%*	*30.8%*

The observed split of traffic traveling left-to-right (a combination of traffic from the other three approaches) is (assuming north direction upwards):

NB-R	*EB-TH*	*SB-L*
37.3%	*60.0%*	*2.5%*

In the following paragraphs, a summary and conclusions are presented as are recommendations for this type of site. Detailed results (graphs) are presented in appendix 9.

Summary and Conclusions Based on Model 5 (Site 3)

Based on the combined results for average driveway-related delays and 50% queue lengths, the conclusions are:

- An increase in MV has more impact on the average delay and queue length of the mainline traffic than increases in DV. Although, the driveway is located "after" the intersection, and is not impacted by the blocking of queue lengths in the directly-adjacent mainline traffic, the delays obtained are very high due to the lack of lanes. The left-turn-out traffic has to wait for the queue (from the signal, going the opposite direction) to clear and thus adds to the left-turn-out delay. Similarly, left-turn-in delay is also impacted due to high volume on single through lane.

- The negative impact due to increases in DV and LT was greater when CC < 150ft as opposed to 250ft or higher.

- The left turn out traffic was more negatively affected by increases in MV, DV and LT as opposed to left turn in traffic.

- When MV approached 1000vph, the driveway was blocked for all values of CC and all combinations of DV and LT.

- RT-in/out+LT-in only and full access driveway types produced relatively larger delays as compared to other driveway types due to LT in and out traffic.

Evolving Guidelines Based on Model 5 (Site 3)

Based on the foregoing, the following access guidelines are recommended for a development located at a corner **after** a signalized intersection where the approach geometry on the near side is one through lane, and the far side is one left-turn and one shared through and right lanes (no exclusive right-turn lane):

1) When CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.

2) When 100<CC≤150ft, left turns in may be allowed as long as MV<500vph, DV≥150-200vph, and LT<50vph. Left turns out may be allowed as long as LT<10vph, with same conditions of MV and DV.

3) When 150<CC≤250ft, both left turns in and out may be allowed as long as long as MV<500vph, DV≥150-200vph, and LT<50vph.

4) When 250<CC≤350ft, the criteria for left turns in and out are as above.

5) When CC>350ft, the criteria for both left turns in and out stay the same as above as long as the driveway stays within 450ft.

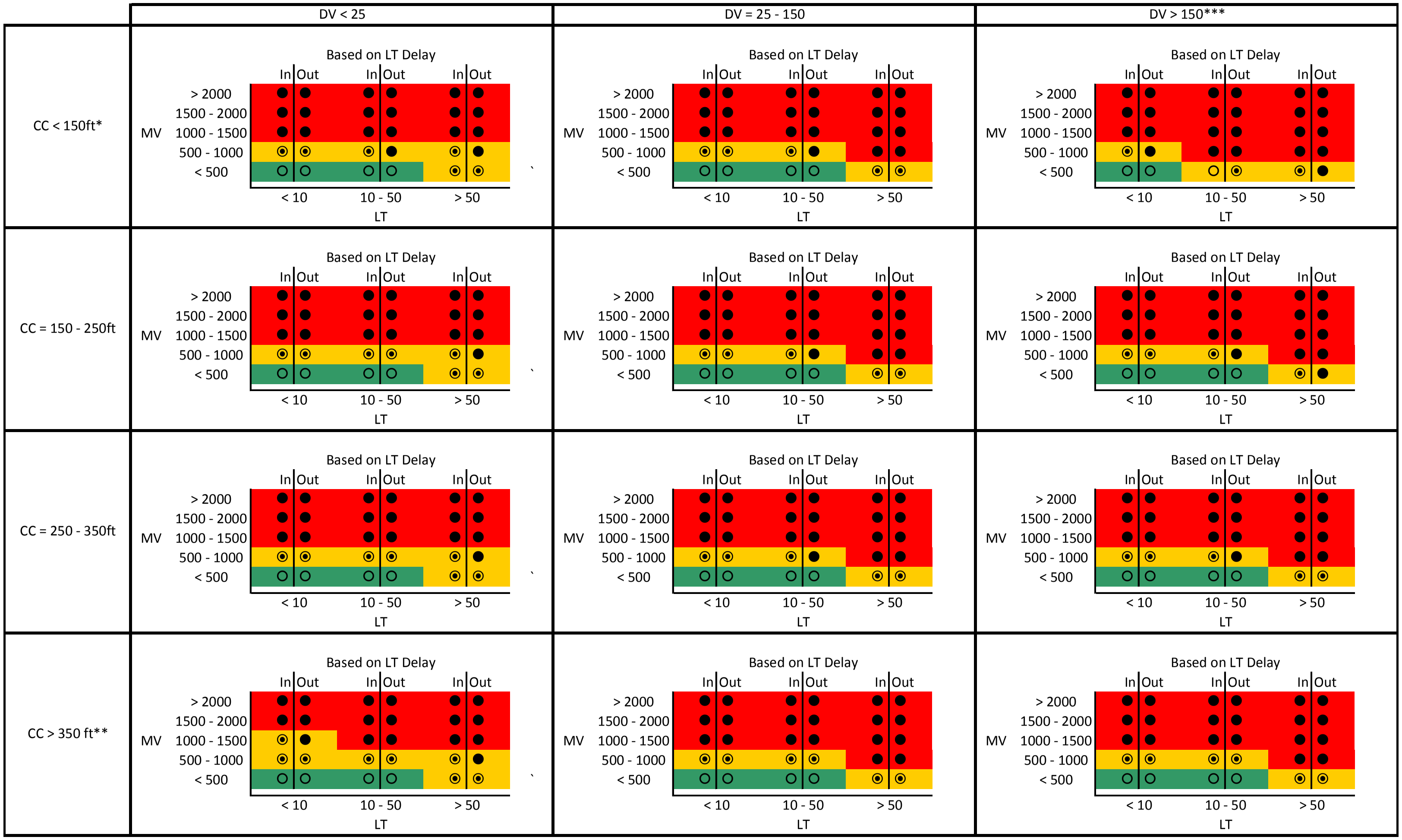
6) Caution must be exercised for allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

These recommendations are summarized in the following chart.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 5

Type: Corner Site "After" Intersection
Number of Lanes: (Near Side) 1 Through, (Far Side) 1 Left, 1 Shared Through and Right
Percentage Split of Mainline Volume at the Study Leg: Left=4.1%, Through=65.1%, Right=30.8%



LEGEND:

- CC = Corner Clearance (ft)
- DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
- MV = Mainline Volume (vph)
- LT = Left Turns In and Out (vph) => Not part of DV
- ● = Prohibit LT
- ⦿ = May Prohibit LT for Higher Values of DV, LT, MV
- ○ = May Allow LT
- [red] = Left Turns In/Out as a "Pair" Should be Prohibited
- [yellow] = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
- [green] = Left Turns In/Out as a "Pair" Maybe Allowed

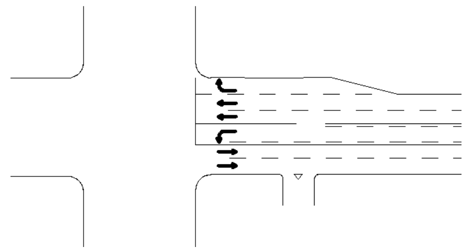
NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.
** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.
*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 19. Summary of Left Turn Restriction Recommendations for Model 5

Results for Model 6 *(lane configuration= (near side of adjacent road) 2 TH lanes; (far side) 1 LT and 2 TH and 1 RT lanes—study site 4)*

Model 6 (site 4) is similar to Model 1 (site 1) in terms of the approach geometry of the intersection. However, this site is located AFTER the intersection rather than before.



The observed split by turning movement (for traffic flowing to the left in the drawing above) at the intersection is:

Left	*Through*	*Right*
22.8%	*57.3%*	*19.9%*

The observed split of traffic traveling left-to-right (a combination of traffic from the other three approaches) is (assuming north direction upwards):

NB-R	*EB-TH*	*SB-L*
11.7%	*69.0%*	*19.8%*

In the following paragraphs, a summary and conclusions are presented as are recommendations for this type of site. Detailed results (graphs) are presented in appendix 10.

<u>Summary and Conclusions Based on Model 6 (Site 4)</u>

Based on the combined results for average driveway-related delays and 50% queue lengths, the conclusions are:

- Similar to previous models, an increase in MV has more impact on the average delay and queue length of the mainline traffic than increases in DV.
- The negative impact due to increases in DV and LT was greater when CC < 150ft as opposed to 250ft or higher.
- The left-turn-out traffic was more negatively affected by increases in MV, DV, and LT than left-turn-in traffic.

- When MV approached 1500vph, the driveway was blocked for all values of CC and all combinations of DV and LT.
- RT-in/out+LT-in only and full access driveway types produced relatively larger delays compared to other driveway types due to LT-in and -out traffic.

Evolving Guidelines Based on Model 6 (Site 4)

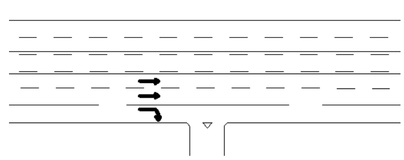
Based on the foregoing, the following access guidelines are recommended for a development located at a corner **after** a signalized intersection where the approach geometry on the near side is two through lanes, and the far side is one left-turn, two through, and one right-turn lanes:

1) When CC≤100ft and MV≥ 500vph, left turns in and out of the driveway should be prohibited.
2) When 100<CC≤150ft, left turns in may be allowed as long as MV<1000vph, DV≤150vph, and LT<10vph. Left turns out may be allowed as long as MV≤ 500vph, DV~150-200vph, and LT<10vph.
3) When 150<CC≤250ft, the criteria for left turns stay the same. Left turns out may be allowed as long as MV<1000vph, DV≤25vph, and LT<50vph. The criteria for left turns out stay the same.
4) When 250<CC≤350ft, left turns in may be allowed as long as MV<1000vph, DV≤150vph, and LT<50vph. Left turns out may be allowed as long as MV≤ 500vph, DV~150-200vph, and LT<50vph.
5) When CC>350ft, left turns in may be allowed as long as MV< 1000vph, DV~150-200vph, and LT<50vph as long as CC<450ft. The criteria for left turns out stay the same as above.
6) Caution must be exercised for allowing left turns for greater values of MV, as it may well result in blocking the driveway by queues, even if CC approaches 450ft.

These recommendations are summarized in the following chart.

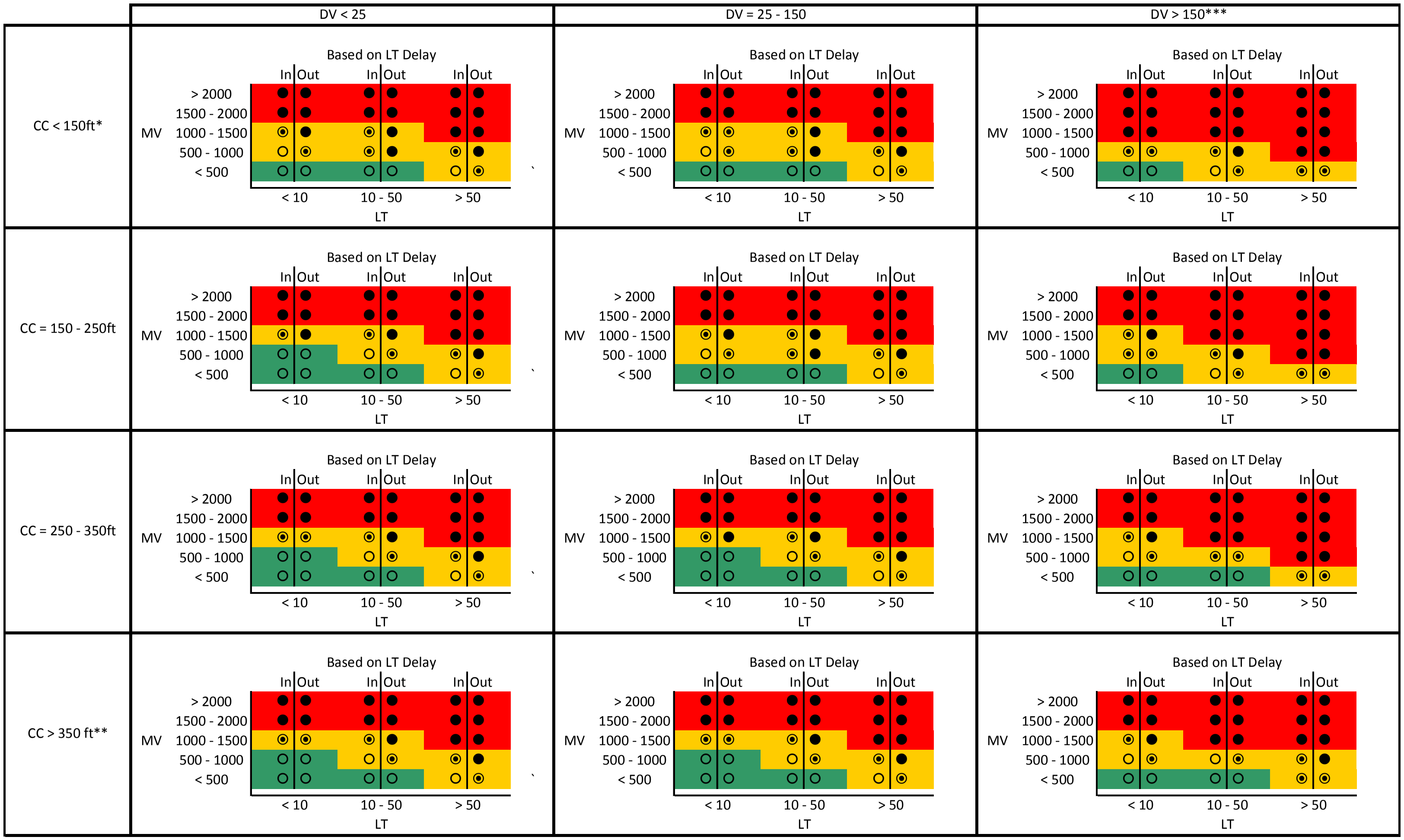
Results for Model 7 *(lane configuration (near side) = 2 TH, 1 LT, and 1 auxiliary lane (RT-in/out)—study site 2)*

This site is substantially different from those previously discussed insofar as this model is for a mid-block scenario (not a corner site). The site is a typical arterial roadway type. It may be found in urban/suburban commercial areas, a basic 5-lane section with an auxiliary right-turn in/out lane.



RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 6 **Type:** Corner Site "After" Intersection
Number of Lanes: 2 Through
Percentage Split of Mainline Volume at the Study Leg: Left=22.8%, Through=57.3%, Right=19.9%



LEGEND:

CC = Corner Clearance (ft)
DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
MV = Mainline Volume (vph)
LT = Left Turns In and Out (vph) => Not part of DV
● = Prohibit LT
⦿ = May Prohibit LT for Higher Values of DV, LT, MV
○ = May Allow LT
(red) = Left Turns In/Out as a "Pair" Should be Prohibited
(yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
(green) = Left Turns In/Out as a "Pair" Maybe Allowed

NOTES:

* CC of 150ft was used in the simulations. If the CC is <= 100ft, then LT restrictions will apply even for lower ranges of MV.
** CC of 350ft was used in the simulations. If the CC is much higher than 350ft, then LT restrictions can be relaxed for higher ranges of MV.
*** DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 20. Summary of Left Turn Restriction Recommendations for Model 6

Selected graphs and detailed results are provided in appendix 11.

Summary and Conclusions Based on Model 7 (Site 2)

In the case of a mid-block sites, the conclusion related to left-turn prohibition is primarily based on the average delay related to left-turn-in and -out traffic. The maximum queue lengths within the driveway show how long the queues become for a particular range of MV, DV, and LT, and can be problematic for the development's traffic operation. The comments that follow are based on the graphical results shown in the appendix:

- Increase in MV has more negative impact on the average delay for left-turn-in and -out traffic than increases in DV.

- Left-turn-out traffic was more negatively affected by increases in MV, DV, and LT than left-turn-in traffic. This is due to the longer distance needed to be covered by the left-turn-out vehicles as opposed to left-turns-in. Left-turn-out vehicles waited relatively longer due to the requirement of a gap in both near-side **and** far-side mainline traffic.

- When MV approached 1500vph, the left-turn-out traffic was practically jammed for all values of DV and LT. Left-turn-in traffic was able to enter the facility as long as it was low (<10vph).

Evolving Guidelines Based on Model 7 (Site 2)

Based on the foregoing, the following guidelines are recommended for a mid-block development where the approach geometry on the near side is two through lanes, and one auxiliary lane for right-turn in/out traffic:

1) When MV>1500vph, left turns in and out should be prohibited.

2) When 1000<MV≤1500vph, left turns out should be prohibited; however, if MV is less than 1200vph, left turns in may be allowed as long as LT <50vph and DV<150vph.

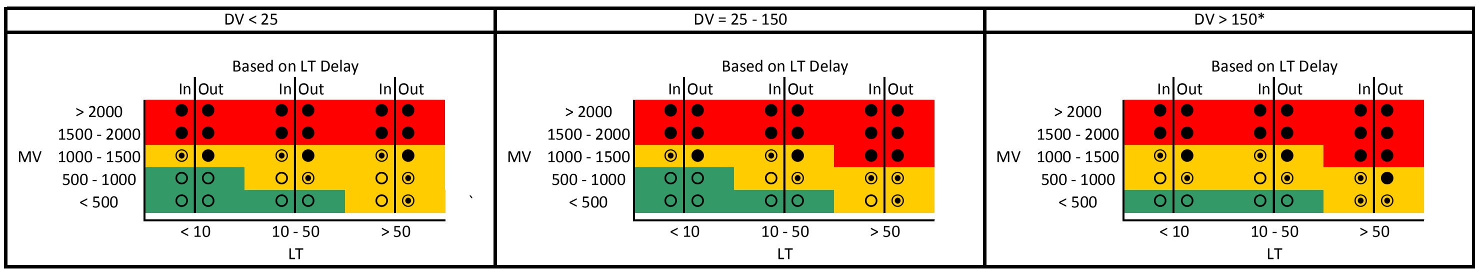
3) When 500<MV≤1000vph, left turns in can be allowed as long as DV≤200vph and LT≤50vph. Left turns out should be prohibited if DV≥150vph and LT≥50vph.

4) When MV<500vph, left turns in and out can be allowed as long as DV<150vph and LT≤50vph; and, may be allowed for higher values of DV (i.e. up to approximately 200vph). In addition, left turns in may also be allowed if DV<150vph and LT>50 (up to approximately 100vph).

These recommendations are summarized in the following chart.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 7 **Type:** Mid-block Site
Number of Lanes (near side): 2 Through, 1 Auxiliary (RT in/out)



LEGEND:

CC = Corner Clearance (ft)
DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
MV = Mainline Volume (vph)
LT = Left Turns In and Out (vph) => Not part of DV
● = Prohibit LT
⊙ = May Prohibit LT for Higher Values of DV, LT, MV
○ = May Allow LT
(red) = Left Turns In/Out as a "Pair" Should be Prohibited
(yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
(green) = Left Turns In/Out as a "Pair" Maybe Allowed

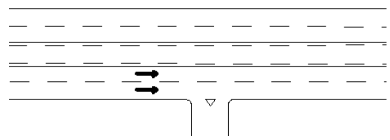
NOTES:

* DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 21. Summary of Left Turn Restriction Recommendations for Model 7

Results for Model 8 *(lane configuration (near side) = 2 TH lanes—study site 6)*

Site 6 is a stereotypical 5-lane suburban arterial. It differs from other models (except the immediately preceding one) in that it is a mid-block site.



Detailed results are shown in appendix 12.

Summary and Conclusions Based on Model 8 (Site 6)

Following are the salient conclusions:

- Similar to Model 7, increases in MV have more negative impact on the average delay for left turn-in and -out traffic than increases in DV.

- The left-turn-out traffic was more negatively affected by increases in MV, DV, and LT than was left-turn-in traffic. The left-turn-out delay was relatively less as compared to Model 7. This can probably be attributed to the fact that the proportional mainline volume for the far side traffic was relatively less (-17.2%) for Model 8 than Model 7 (+64.3%)—this means that larger gaps were available for left-turn-out traffic for Model 8.

- When the MV approached 2000vph, the left-turn-out traffic was practically jammed for all values of DV and LT, except when DV<25vph and LT<10vph. Left-turn-in traffic was able to enter the facility as long as it was less than 10vph.

Guidelines Based on Model 8 (Site 6)

Based on the foregoing, the following access guidelines are recommended for a mid-block development where the approach geometry on the near side is two through lanes without any auxiliary lane for right-turn in/out traffic:

1) When MV>2000vph, left turns in and out should be prohibited.

2) When 1500<MV≤2000vph, left turns out should be prohibited. Left turns in may be allowed as long as MV<1700vph, DV<200vph, and LT<10vph.

3) When 1000<MV≤1500vph, left turns out should be prohibited if DV>25vph and LT>10vph. Left turns in may be allowed as long as LT<10vph and DV<150.

4) When 500<MV≤1000vph, left turns out should be prohibited if DV≥150vph and LT≥50vph; and, may be allowed if DV<25vph and LT<50vph. Left turns in can be allowed as long as DV<200vph and LT<50vph.

5) When MV<500vph, left turns in and out can be allowed as long as DV<150vph and LT≤50vph; and, may be allowed for higher values of DV (i.e. up to approximately 200vph). In addition, left turns in may also be allowed if DV<150vph and LT>50 (up to approximately 100vph).

These recommendations are summarized in the following chart.

OVERARCHING RESULTS AND RECOMMENDATIONS

Based on the results from the safety and operational analyses, overall results and recommendations can be presented. First, the results from the operational modeling of different roadway configurations were reviewed which showed certain similarities. These are presented below, followed by the general access guidelines (broken down by corner and mid-block sites).

SUMMARY OF RESULTS FROM OPERATIONAL MODELING OF DIFFERENT ROADWAY CONFIGURATIONS

- An increase in MV has relatively more impact on the average delay and queue length for the mainline traffic than an increase in DV.
- The negative impact due to increases in MV, DV, and LT was greater when CC was less than 150ft as opposed to 250ft or more.
- When the MV approached 2000vph, the driveway was typically blocked for all values of CC and all combinations of DV and LT.
- The impact of minimum and maximum DV on the average delay was greater as MV approached 1500vph.
- The delay for LT-out traffic was typically greater than delay for LT-in traffic.
- For corner sites, the 50^{th} percentile queue length blocked the driveway when the mainline volume reached more than 1500vph. The maximum CC used was 350ft.

GENERAL ACCESS GUIDELINES BASED ON OPERATIONAL MODELING

Corner Sites

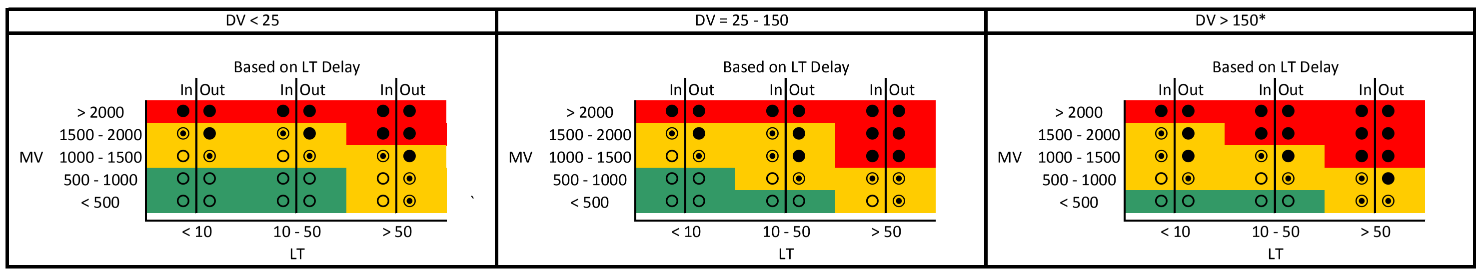
For corner sites on a basic 5-lane section adjacent to the development (for sites both “before” and “after” the intersection), the following are the guidelines:

1) When CC≤100ft and MV≥500vph, left turns in and out of the driveway should be prohibited for any volume of DV and LT.

RESULTS FOR LEFT TURN IN/OUT RESTRICTION RECOMMENDATIONS

MODEL 8

Type: Mid-block Site
Number of Lanes (near side): 2 Through



LEGEND:

CC = Corner Clearance (ft)
DV = Driveway Volume (vph) => Entering from the Adjacent Traffic (from Near-Side Lanes)
MV = Mainline Volume (vph)
LT = Left Turns In and Out (vph) => Not part of DV
● = Prohibit LT
⊙ = May Prohibit LT for Higher Values of DV, LT, MV
○ = May Allow LT
(red) = Left Turns In/Out as a "Pair" Should be Prohibited
(yellow) = Left Turns In/Out as a "Pair" Maybe Prohibited for Higher Values of DV, LT, MV
(green) = Left Turns In/Out as a "Pair" Maybe Allowed

NOTES:

* DV of 150vph was used in the simulations. If the DV is much higher than 150vph, then LT restrictions will become more strict for higher ranges of MV.

Figure 22. Summary of Left Turn Restriction Recommendations for Model 8

2) When MV≥1500vph, left turns in and out should be prohibited for any combination of CC, DV, and LT.

3) When 1000>MV≥1500vph, left turns in and out should be prohibited if DV>150vph and LT>50vph for any CC.

4) When 500>MV≥1000vph and LT≥50vph, an extra care should be taken before allowing left turns in and out. For MV closer to 1000vph, the left turn prohibition criteria would become more important.

5) Caution must be exercised in allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

For other corner sites (i.e., on basic 3-lane or 2-lane [no TWLTL] sections),the following guidelines are recommended regardless of whether the site is "before" or "after" the intersection:

1) When CC≤100ft, left turns in and out of the driveway should be prohibited for any combination of CC, DV, and LT.

2) When MV≥1000vph, left turns in and out should be prohibited for any combination of CC, DV, and LT.

3) When 500>MV≥1000vph, left turns in and out should be prohibited if DV>150vph and LT>10vph for any CC.

4) Similarly, caution must be exercised in allowing left turns for greater values of MV, as it would result in blocking the driveway by queues, even if CC approaches 450ft.

Mid-Block Sites

1) When MV≥1500vph, left turns in and out are recommended to be prohibited for any combination of DV and LT.

2) When 1000>MV≥1500vph, left turns in and out should be prohibited if DV>150vph and LT>50vph. For lower volumes of DV and LT, restrictions would be more important as MV approaches 1500vph.

3) When MV≤1000vph, LT<10vph (may go up to 20vph) and DV<25vph (may go up to 50vph), left turns in and out can be allowed.

4) Even if MV<1000vph, caution must be exercised for allowing left turns, especially for higher values of DV and LT.

Overarching Safety Considerations

Compared to the operational concerns, safety considerations were viewed as being less significant since the crash reductions that might be expected from access restrictions appeared to be relatively modest. This observation is consistent with earlier research. Moreover, crash reductions appear to be relevant only in situations where the ADT is relatively high—greater than 15,000 vpd (which roughly corresponds to a peak hour volume of 1200-1800 vph). Thus, the most problematic volumes for operational concerns roughly coincide with those for safety. That is, overlaying safety concerns with operational issues does not significantly change any of the guidelines. That being said, it was clear from the safety-related review that there is considerable variation in crash history by site. So, crash histories should always be reviewed when specific sites are being reviewed/evaluated for implementation of access control measures.

Discussion

In general, the driveways are designated as either full access or right-in-right-out, the main focus of the project was to observe and determine under what conditions left turns in and out of the facility become problematic and must be restrained. Right-turn (in or out) driveway traffic is generally not critical from either the operation or safety perspectives as opposed to left-turn traffic due to fewer conflict points. The consideration of right-turn-out delays was not highlighted due to similar results for almost all the models. It was observed that for sites with a basic 5-lane section (including mid-block sites), the right-out delays were higher than the acceptable LOS when the CC<150ft, MV>1000vph, DV>150vph, and MV>50vph. For CC ≥250, the MV could be up to 1500vph. Similarly, for basic 2- and 3-lane sections, the right-out delay was beyond the acceptable limits when CC<150ft, MV>500vph, DV>150vph, and MV>1000vph.

When applying any of these guidelines, it should be remembered that all of the operations modeling was done using hourly volumes. These ranged from very low numbers to near-capacity conditions. Most importantly, the operational problems typically arose at the higher end of that range. What this means is that the problems noted are generally occurring during peak or otherwise high volume hours/situations—at other times of the day, the problems (e.g., delays and queues) would be much less apparent. Put another way, there may well be only a couple of times in a day when access restrictions are really necessary.

One aspect of access control that was not covered in this project was the actual design of the access control (e.g., required shape and size of channelizing island). During the observations done at the nine sites, turning violations were often noted—i.e., even though left turns in and/or out were prohibited, many drivers made (or attempted to make) the turn anyway. This was, for example, routinely observed at the MSUFCU on Saginaw (site 2) where drivers went around and even over the small raised island that was meant to prohibit turns. The point of mentioning that here is that whenever turns are restricted, significant islands and signs must be used if drivers are really going to be expected to not make the prohibited turn(s).

It should be noted that the guidelines developed and presented here should be carefully applied, based on proper geometrical, volume, and signal data gathered in the field. Any specific site may present some factors (or local conditions) which need to be studied "on-site" to come up with conclusions regarding restricting or allowing left turns related to the development. Different sites may have similar geometric configurations as the study sites selected for this project; however, they might have different volume percentage splits at the intersection, speed limit, signal phases, driveways of adjacent/nearby developments, and other landscape/visual obstructions-related factors. Therefore, it is highly recommended to investigate each site individually before applying these guidelines.

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Appendix 1. Summary of Turn-Restriction Practices

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection		
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)		
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria		Min Distance(ft)
	NCHRP reports	AASHTO advises that driveways not to be permitted within the functional area of an intersection, therefore there should be sufficient corner clearance to separate access connections from roadway intersections.Where no alternatives exist, common practice is for the permitting department to allow construction of an access connection along the property line farthest from the intersection.In such cases, agencies typically reserve the right to require directional connections (i.e., right-in/out, right in only, or right out only) or to require nonconforming corner properties to share access with abutting properties. **(Access Management Manual 2003)**	No information was found when left turns are allowed,but can be derived from the information given in RT-in/out column.	Not addressed specifically, but can be derived from the turning restrictions.	**Design Condition**	**Throat width**			**Speed**	**Spacing (feet)[(1)]**		**Speed**	**IMCC**
					Single-lane exit, entering passenger car must wait until an exiting vehicle clears the driveway	25			20	120		30	325
					Simultaneous entry and exit by passenger cars	35			25	190		35	425
					Simultaneous exit by passenger car and entry by single-unit truck	40			30	320		40	525
					Separate left-turn and right-turn exit lanes for passenger cars and simultaneous entry by passenger car	43			35	450		45	630
					Simultaneous entry and exit by single-unit trucks	40			40	620		50	750
					All above mentioned widths are for driveways with no bike lane				45	860		55	875
					Access Management Manual 2003				50	1,125		60	1005
									55	1,500			
									60	1,875		**IMCC**=Initial minimum corner clearance distances for under saturated conditions. Corner clearance for different traffic conditions can be adjusted by multiplying IMCC with adjustment factors.	
									(1) 1.5 times the distance required for a passenger car on level terrain to accelerate from zero to through traffic speed based on acceleration information from NCHRP Report 270 as contained in the 1990 AASHTO Green Book			**NCHRP Report 420 (1999)**	
									Transportation Research Circular No 456,March 1996				
Alabama	Not available online												
Alaska	Not available online												
Arizona	Not available online												
Arkansas	Not available online												
California	Not available online												
Colorado	State Highway Access Code March 2002	Channelized driveway islands may be required for turn restricted driveways when the driveway volume is predicted to exceed 100 DHV, no restrictive center median is in place or programmed to be constructed or it is likely that there will be frequent violations of the turn restrictions.	When private access is permitted, left turns may be allowed if in the opinion of the department such left turns can be reasonably accomplished and it is not a divided highway. *(See details in description)*	Not addressed specifically, but can be derived from the turning restrictions.	SUVV* ≤5 DHV**	16	30		25	150			
					SUVV>5 DHV or if multi-unit vehicles present	25	40		30	200			
									35	250			
									40	325			
					* Single Unit Vehicular Volume				45	400			
					** Design Hourly Volume				50	475			
									55	550			
									60	650			
									65	725			
									70	850			
Connecticut	Not available online												
Delaware	DelDOT Manual	Right-turn in/out only driveways are controlled with proper channelization and pavement markings.	Left turns are allowed where design meets all safety requirements *[undefined]*. Median cross-over and channelization is provided to account for both right and left turns. Storage lanes should be provided by checking the volume warrants for left-turn lane.	Not addressed specifically, but can be derived from the turning restrictions.	For residential access within subdivision streets	12	20	Category 2: Principle arterials		400	L=N/28*20 where L = back of shoulder at intersection to center line of enterance; N = No of vehicles expected to approach the intersection in design hour.		50
					Combined residential entrance serving two residential properties	24	30	Category 3: Collectors (minor arterial or major collector)		250			
								Category 4: Local (minor collectors or local roads)		200			
								Spacings given are for residential access only					
Florida	Driveway Handbook March 2005	Where minimum corner clearance cannot be met, due to specific site conditions,you should at least try and get 125 to 230ft of corner clearance. In these cases it is most important to prohibit(or limit) left turns from these driveway locations.Right turn in/out only driveway is provided with "pork-chop channelization" and with appropriate signs like "Do Not Enter" or "Right Lane Must Turn Right" or with flexible posts on main road to discourage left turns.	Left turns exiting the driveway are permitted but for that, separate left turn lane is to be provided in the driveway.	Full access is allowed with appropriate median crossover spacing, auxiliary lanes on the highway, adequate channelization and dedicated lanes for all movements.	**Trips/Day**(at driveway) **Trips/Hour**				Median Treatment and Access Roads		Position	Access Allowed	
					1-20 1-5	12	24	***Generally Developing or Undeveloped***			***With Restrictive Median***		
					21-600 6-60	24	36	2	Roads	*1320/660	Approaching Intersection	Right In/Out	115
					601-4000 61-400	24	36	3	Restrictive	660/440	Approaching Intersection	Right In Only	75
								4	Non-Restrictive	660/440	Departing Intersection	Right In/Out	230(125)*
								Generally Developed			Departing Intersection	Right Out Only	100
					Driveway width standards are same both for rural section (flush shoulder) and urban section (curb & gutter)			5	Restrictive	440/245	***Without Restrictive Median***		
								6	Non-Restrictive	440/245	Approaching Intersection	Full Access	230(125)*
								7	Both Median Types	125	Approaching Intersection	Right In Only**	100
										* >45 mph / ≤45 mph	Departing Intersection	Full Access	230(125)*
											Departing Intersection	Right Out Only**	100
											For * and **, refer to description		
											Corner clearance has been taken from the document "Access management standardsds-Rule 14-97"		

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements: Restrictive Access – RT-in/out	Restrictive Access – LT-in/out	Full Access	Driveway Width: Width Criteria – Vehicular Volume/Type of Driveway	Width of Driveway – Min (ft)	Width of Driveway – Max (ft)	Driveway Spacing: Spacing Criteria – Access Class	Median Type or Speed (mph) or Control	Min Driveway Spacing(ft)	Corner Clearance at Intersection (Distance of Driveway from the Intersection): Criteria	Min Distance(ft)
Georgia	Driveway Manual (March 2,2004)	Raised islands are used to channelize the movements at a driveway where only right turns are allowed.	LT-in/out allowed with appropriate median opening design.	Full access is allowed with GDOT detailed Design for Median Crossovers on Divided State Highways.	Current Residential GA Std.	14	18		25	125		
					Current Commercial (One Way) GA Std	16	20		30	125		
					Current Commercial (Two Way) GA Std	24	40		35	150		
									40	185		
									45	230		
									50	275		
									55	350		
									60	450		
									65	550		
Hawaii	Not available online											
Idaho	Not available online											
Illinois	Not available online											
Indiana	INDOT Driveway Permit Manual 1996	Major driveways into developments such as shopping centers should be constructed to prevent cross traffic movement of internal traffic within 100ft from the highway edge of pavement.This may be accomplished by the use of a raised island.	Where left turns are needed,dedicated left turn lanes should be provided on the driveway for required level of service above "C",and left turns deceleration lanes on the highways should also be provided to enter the approach safely.High volume traffic generators such as shopping centers, industrial plants,industrial parks, residential projects,and similar developments may have a median crossover desirable.	Not addressed specifically, but can be derived from the turning restrictions.	1-way access	16	24		30	185	Att signalized intersections,the minimum corner clearance should be equal to the average signal queue length.	
					2-way accesses if the single-unit vehicle volume<5DHV	16	24		35	245	At unsignalized intersections,corner clearance distances need only be sufficient to ensure adequate and unrestricted turning movements by driveway traffic.	
					For 2-way access,if any of the following apply;(a) Vehicle volume exceeds 5DHV(b) Multi-unit vehicles will use the access(c) Single-unit vehicles of more than 30' in length will use the access(d)Vehicles of more than 16' in width will use the access.	25	35		40	300		
									45	350		
									50	395		
									55	435		
Iowa	Iowa Primary Road Access Management Policy December 2005	The department reserves the right o close an existing median opening when the department deems it is necessary.	Median opening should not be permitted except to accommodate,large traffic-generating facilities such as large shopping centers or industrial plants.Median openings may be permitted in these instances if satisfactorily justified to account for turning movements.	Not addressed specifically, but can be derived from the turning restrictions.	Residential driveway	10	28	Local street		150	Local streets	30
					Commercial and multifamily driveway	24	36	Collector		185	Collector streets	75
								Minor arterial		230	Minor arterial	100
								Major arterial		275	Major arterial	120
											Note:These measurements shall be taken from intersection of property lines at the corner to the edge of driveway.	
Kansas	Corridor Management Policy	Driveway channelization has been used on the sketches given by Ksdot Manual,but did not address clearly on right turn in/out only driveways.	Median crossovers,existing prior to construction of a driveway or local road,may require modification to accommodate the projected traffic movements. Cost incurred for such modifications will be borne by the owner.	Not addressed specifically, but can be derived from the turning restrictions.		Two Way Access						
					Low Vol(Type1& 2)	12	30	1,2,3, & 4	Developed	205		
					Commercial Type 4, 5 &6	24	36	5 & 6	Developed	340		
					Industrial Type 5& 6	24	40	1,2,3,& 4	Undeveloped	2640		
					Joint use Type 1,2 ,4,5 & 6	[2]	[2]	5 & 6	Undeveloped	430		
						One Way Access						
					Low Vol(Type1& 2)	12	24					
					Commercial Type 4, 5 &6	12	24					
					Industrial Type 5& 6	*[1]20	*[1]40					
					Joint use Type 1,2 ,4,5 & 6	*[2]	*[2]					
					Note: Driveways which are channelized with a median island separating the egress and ingress vehicular movements will use the appropriate one-way dimensions on this chart.							
Kentucky	Access Management Guidance	In extreme cases, where corner clearance is not sufficient,a right-in/right-out entrance may be considered, provided a non-traversable median is constructed to prevent left turns.	If access point are off-set, then right-in/right-out entrances shall be utilized.	Median openings allowing full access cannot be evaluated independent of direction. Median openings are allowed only when spacing requirements can be met for both sided of the roadway.	**Trips/Day** / **Trips/Hour**							
					1-20 / 1-5	12	24	1	Restrictive	1200/600		
					21-600 / 6-60	24	36	2	Restrictive Preffered	600/400		
					601-4000 / 61-400	24	36	3	Non-Restrictive	400/300		
								4	Non-Restrictive	150*/125		
Lousiana	Not available online											
Maine	Highway Driveway and Entrance Rules	Right-turn in/out only driveways were not specifically addressed.	Minimum safe sight distance must be provided for the vehicles turning left from a major roadway.Two-way left turn lanes may be provided onto a Mobility Arterial to accommodate left turns, as a MaineDOT mitigation of traffic imapcts from a proposed entrance.	Not addressed specifically, but can be derived from the turning restrictions.	Driveway onto any highway locate outside urban compact areas	12	22		*Posted Speed (mph)*			
									25 or less	Not Applicable		
					Driveway onto a Mobility Arterial	12	22		30	Not Applicable		
					Commercial/Industrial Entrance onto Curbed/Uncurbed Highways		42		35	Not Applicable		
									40	175		
					Residential Entrance onto Curbed Highways	20			45	265		
									50	350		
									55 or more	525		
					A waiver is required for special case							

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection		
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)		
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria		Min Distance(ft)
Maryland	State Highway Access Manual	Commercial right-in/right-out entrances shall be used on all divided highways with posted speeds above 40 mph. Alternatively,in urban street environments where posted speeds are 40 mph or lower and a narrow raised median separates the directional highways, other commercial entrances may be used as long as appropriate signing is provided to discourage errant movements.	In one-way commercial entrances, directional control restricting left turns may be provided.	Commercial two-way entrances are acceptable along a divided highway only if there is an approved full movement median opening at the site access, whereas on undivided highway commercial two-way entrances are appropriate where no turning movement restrictions is required.	Commercial Twoway entrances Commercial Oneway entrances RightIn/RightOut Entrances if commercial vehicle present RightIn/RightOut Entrances if Predominantly passenger cars	25 17 Min 20' one way width Min 17' one way width	35 20	A minimum 20' tangent is required between adjacent entrances on the same side of Highway under any circumstances.			**Highway classification** Primary Secondary-Arterial Secondary-Collector *On primary highways,entrances may not be located within the influence area of dedicated right or left turning lanes for the adjacent intersection.	**Preffered distance** 400* 200 150	**Minimum distance** 200* 100 75
Massachusetts	Not available online												
Michigan	MDOT Manual (currently not available online)	In order to separate conflicting turning movements into and out of property, "right-in only", "right-out only" or "left-turn only" access by channelization islands may be effective.Particularly on corner properties,allowing "right-turn only" in and out can cut down on left-turns near intersections.However, raised medians are the most effective practice to reduce conflicts associated with left turns.	Not addressed specifically, but can be derived from the turning restrictions.	Not addressed specifically, but can be derived from the turning restrictions.	Single driveway or two-family driveway Two-way driveway	9	16 30		Speed on Roadway (mph) 25 30 35 40 45 50 55	Spacing 130 185 245 300 350 455 455+	Signalized Intersection Control Stop Sign Intersection Control Note: These values assume a 30 to 35 mph posted speed. For a posted speed of 40 to 55 mph, these values should be doubled.	 230 ft 115 ft	
Minnesota	Access Management Manual	On existing roadways, the entrance should be limited to right-in/right-out only, unless weaving or other traffic operations indicate the need for further restrictions on turning movements (e.g. right-in only or right-out only). On the planned divided roadways, access will be limited to right-in/right-out movements when the median is constructed.	Residential, commercial, industrial or institutional uses may be granted additional access if it is determined to benifit site circulation and overall corridor operations. If multiple access points are being considered, the additional access points may be limited to 3/4 movement (right-in/right-out/left-in only), right-in/right-out only, right-in only,or right-out only.	Not addressed specifically,but can be derived from the turning restrictions.	A minimum 20' tangent is required between adjacent entrances on the same side of Highway under any circumstances.				**Posted Speed Limit (mph)** 40 45 50 55 60 65	**Rural(Type1& 2) Rural & Urban/Urbanizing(Type 3)** (feet)(2)(4) (feet) (1)(2)(3) ... 305 50 360 75 425 100 495 100 570 ... 645			
Mississippi	Not available online												
Missouri	Not available online												
Montana	Not available online												
Nebraska	Access Control Policy to the State Highway System							Rural Undeveloped Urban Urban	**No of Access locations per mile** 3** 7** Provide access to all properties**	1000 600 Consider Consolidation of drives			
Nevada	Access Management System and Standards	Driveway spacings are based on speed to reduce collision potential due to right-turn conflict overlaps as well as providing reasonable egress capacity.	Not addressed specifically.	Not addressed specifically.	Class I (Non Commercial) ClassII(Minor Commercial) Class III(Major Commercial) For SU For WB-50	12 32 32 *16 *16 *May alter depending on curb radius.	24 48 Max width depends on the lane requirement and traffic impact report. *22 *26		**85th Percentile Speed (mph)** 25 30 35 40 45 50 55 60 65 70	 150 200 250 300 350 450 600 800 1000 1200			
New Hampshire	Not available online												

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection	
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)	
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria	Min Distance(ft)
New Jersey	State Highway Access Management Code (Publidhing date not mentioned, expires on April 11, 2012)	(1)If future traffic volumes could warrant installing a traffic signal and signalized spacing requirements cannot be met , as a condition of the access permit, the commissioner may, at such time as future volumes are reached ,close the left turn access in accordance with N.J.A.C. 16:47-4.33(b).(2) If an undivided highway becomes divided, as a condition of the access permit,the Commissioner may at such time close the left-turn access in accordance with N.J.A.C. 16:47-4.33(b).	Left turn access shall be prohibited if the criteria for left turn lane have been met but there is insufficient space for a left turn lane,unless the commissioner determines that left-turns can be made safely,considering traffic volumes and sight distances.	Not addressed specifically,but can be derived from the turning restrictions.	Residential	8	26		Posted speed limit	Spacing Distance	For single-family residential driveway	12
					Non -residential				20	85	All driveways in the vicinity of unsignalized intersections, except for single-family residential driveways, on any one of the following:	50
					One-way operation	20	Max desireable=34 Max allowable=40		25	105		
									30	125		
					Two-way operation	20	Max allowable=46		35	150	(i) All access level 6 roadways;	
					Fire house		Max allowable=100		40	185	(ii) All roadways with a posted speed limit of 25 miles per hour; or (iii) All locations with at least a 10 foot shoulder	
									45	230		
									50	275		
									55	330	All driveways in the vicinity of signalized intersections and locations not covered in criterion 1 and 2 above	100
New Mexico	State Access Management Manual	Restrictions to full left-turn access may be required due to safety or operational deficiencies that would be expected if a full access median was implemented.Restricted movements to right-in/out only, should be prohibited through geometric design and channelization	Medians should be designed to accommodate the largest design vehicle anticipated to use the access, and may provide either partial or full access.	Median openings at intersections or full-access driveways should be spaced with a minimum frequency based upon the access category and posted speed of the highway.						**Non-traversable median** Full Access / Partial Access		
								UPA(Urban Principal Arterial)	≤30mph	1320 / 200		
									35 to 40mph	1320 / 325		
									45 to 50mph	1320 / 450		
									≥55mph	1320 / 625		
								UMA(Urban Minor Arterial)	≤30mph	660 / 175		
									35 to 40mph	660 / 275		
									45 to 50mph	660 / 400		
									≥55mph	1320 / 600		
								UCOL(Urban Collector)	≤30mph	330 / 150		
									35 to 40mph	330 / 225		
									45 to 55mph	660 / 350		
								Same Minimun Spacing requirements with Traversable Median as for Partial Access non-traversable median.				
New York												
North Carolina	Policy on Street and Driveway Access to North Carolina Highways(July 2003)	If access connections have to be located within the functional area due to limited property frontage, the NCDOT may restrict access to "right-in/right-out" or other limited movement treatments.Such driveways must still meet all location and minimum distance requirements.In locations where the sight distance cannot be met on both sides of the driveway location, the driveway may be denied. In some cases, the left turn movements into or out of the driveway may be prohibited.	Highway infrastructure improvements may be necessary for safe and efficient traffic operations when there are high roadway and/or turning volumes of traffic,when the roadway speeds are moderate or high, or where needed due to limited sight distance.Highway infrastructure improvements include, but are not limited to additional through lanes, acceleration lanes, and turn lanes for left and right turns associated with a driveway.	On most state maintained routes, the minimum distance between the centerlines of full movement driveways into developments that generate high traffic volumes should be at least 600 ft.However ,on routes with safety, congestion, or operatioanl problems, 1000 ft or more may be required between the centerline of any left turn access points and any adjacent street and driveways.	Driveway with two-way operations	20	36	Min distance between the centerlines of full movement driveways into developments that generate high traffic volumes		600	Criteria	
					Driveway with one-way operation	12	24				Where the property's road frontage allows	100
											At no time shall it be less than	50
						The need for wider driveways will be considered on a case-by-case basis only after justification of actual necessity, but should not exceed 50 feet.		On routes with safety, congestion and operational problems		1000	For full movement driveway connections at signalized intersections and when the property's road frontage allows	Extend beyond 100'
								High Volume Generator- A land or development that has an average daily traffic greater than 1000 vehicles per day.			Corner clearance is from the point of tangency of the radius curvature of the intersecting streets to the proposed driveway.	
North Dakota												

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements: Restrictive Access: RT-in/out	Rules for Driveway movements: Restrictive Access: LT-in/out	Rules for Driveway movements: Full Access	Driveway Width: Width Criteria: Vehicular Volume/Type of Driveway	Driveway Width: Width of Driveway: Min (ft)	Driveway Width: Width of Driveway: Max (ft)	Driveway Spacing: Spacing Criteria: Access Class	Driveway Spacing: Spacing Criteria: Median Type or Speed (mph) or Control	Driveway Spacing: Min Driveway Spacing(ft)	Corner Clearance at Intersection (Distance of Driveway from the Intersection): Criteria	Corner Clearance at Intersection: Min Distance(ft)
Ohio	Ohio State's Highway Access Management Manual (December 2001)	Left turn movements shall not be permitted if a median is already established and the opening of the median would not provide, in the determination of the Department, any significant operational or safety benefits to the general public or would be counter to the purpose of the median construction and the continued function of the highway at the category assigned to it.	A left turn movement may be permitted if (1) the left turn movement does not have the potential for signalization, and (2) if the Department determines that the left turn movement does not cause congestion or safety problems or lower the level of service, and (3) alternatives to the left turn would cause roadway and intersection operation and safety problems, and (4) does not interfere with operation of the street system or access to adjacent properties.	Not addressed specifically, but can be derived from the turning restrictions.	Nominal Width (Commercial)				Posted Speed (mph)	Min Distance		
					Two-way	26	32		25	155ft		
									30	200ft		
									35	250ft		
									40	305ft		
									45	360ft		
									50	425ft		
									55	495ft		
									60	570ft		
									65	645ft		
Oklahoma	Not available online											
Oregon	Access Management Manual								Speed, mph	Spacing		
									20	120		
									25	190		
									30	320		
									35	450		
									40	620		
									45	860		
									50	1125		
									55	1500		
Pennsylvania	Access Management Model Ordinances for Pennsylvania Municipalities handbook	Driveway channelization is used where it is found to be necessary to restrict particular turning movements at a driveway.	Turn restrictions may also be implemented if the improvements that would be required at a driveway to achieve acceptable levels of service cannot be provided due to constraints or there is a history of high crash rates caused by left turning vehicles.for high and medium volume driveways, channelization islands and medians shall be used to separate conflicting traffic movements into specified lanes to facilitate orderly movements for vehicles and pedestrians.	Not addressed specifically, but can be derived from the turning restrictions.	a. For driveways without curb:			Principal arterial		600	Principal arterial	600
					i) A minimum use driveway	10		Minor arterial		400	Minor arterial	400
					ii) Low and medium volume driveways			Major collector		200	Major collector	200
					for one-way operation	10						
					for two-way operation	20		Note:			Note:	
					iii) The design of high volume driveways shall be based on analyses to determine the number of required lanes.			> Driveway spacing is measured from the end of one driveway radius to			> Corner clearance shall meet the driveway spacing standards	
								the beginning of the next driveway radius.			that are desirable for arterial and major collector roads	
								> Driveways shall be aligned with other driveways and roadways on the			> If the minimum driveway spacing standards cannot be achieved	
								opposite side of the intersecting roadway on arterials and major collector			due to constraints, the following shall apply in all cases:	
					b. For driveways with curb:						i) There shall be a minimum 10-foot tangent distance between the	
					i) A minimum use driveway	12					end of the intersecting roadway radius and the beginning radius	
					ii) Low and medium volume driveways						of a permitted driveway.	
					for one-way operation	12					ii) The distance from the nearest edge of cartway of an	
					for two-way operation	22					intersecting roadway to the beginning radius of a permitted	
											driveway shall be a minimum of 30 feet.	
Rhode Island	The State of Rhode Island and Providence Plantations Rhode Island Department of Transportation "Rules and Regulations Concerning Permission for use of state highway rights-of-way"	Not addressed	Not addressed	Not addressed	Residential	10	20				Rural	40
					Commercial(for oneway use)		20				Urban	20
					Commercial(for twoway use)		35					
					Widths are both for rural and urban driveways.							
South Carolina	Acess and Roadside Management Standards 1996				Urban Commercial (One-way)	14	24		Operating Speed	min c/c spacing	Typical cornerlot commercial driveways	75
					Urban Commercial (Two-way)	24	40		30 or less	100		
					Rural Commercial (One-way)	18	24		35	150		
					Rural Commercial (Two-way)	24	50		40	200		
									45	250		
									50	300		
									55 and above	350		

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection		
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)		
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria		Min Distance(ft)
South Dakota	Road Design Manual (Publishing date not mentioned)	A channelizing island is used in a driveway throat: (1) where left turns are undesirable and there is a need to restrict driveway movements to right-in/right-out on undivided roadways, (2) where there is a high accident rate or frequency related to left-turn movements.	Use median openings to provide separate Left-Turn entrances and exits at major traffic generators. Do median modifications to eliminate Left-Turn out movements (used where there are safety or operational problems due to Left-Turn egress)	Not Addressed specifically, but can be assessed from the turning restrictions.					Urban Developed	100		speed (mph)	(ft)
												30	200
												35	225
												40	250
												45	280
												50	350
												55	425
Tennessee	Not available online												
Texas	Access Management Manual, Revised June 2004	Where adequate access connection spacing cannot be achieved, the permitting authority may allow for a lesser spacing when shared access is established with an abutting property.Where no other alternatives exist, construction of an access connection may be allowed along the property line farthest from the intersection. To provide reasonable acces under these conditions but also provide the safest operation, consideration should be given to designing the driveway connection to allow only the right-in turning movement or only the right-in/right out turning movements if feasible.	Left Turns are allowed with appropriate median cross over spacing and auxilliary lanes on highway.	Not Addressed specifically, but can be assessed from the turning restrictions.					Design Speed (mph)	Driveway Spacing (ft)		Posted Speed (mph)	Distance (ft)
									25	155		<=30	200
									30	200		35	250
									35	250		40	305
									40	305		45	360
									45	360		>=50	425
									50	425			
									55	495			
									60	570			
									65	645			
									70	730			
Utah	Roadway Design Manual of Instruction May 2007	Roadway approaches and driveways that are located too close to an intersection can affect signal operation.In these cases it can be considered to restrict access to "right-in/out" operation only.	Restrictive medians limit left-turns, physically or legally, to defined locations. Nonrestrictive medians allow left-turns at any point along the route.Consider restrictive medians on multilane limited access highways and multilane managed access highways when the DHV is over 2,000.	Not addressed specifically, but can be derived from the turning restrictions.	Residential	10	27		Minor Collector	80	Collector		75
					(Single-Family Duplex Shared Driveways)				Major Collector	85-150	Arterial		150
					Residential	18	30		Minor Arterial	185			
					(Multi-Unit, 5 or more Parking Spaces)				Major Arteial	230-275			
					Commercial				Regional Urban	200			
					(Requiring 5 or more Parking Spaces)								
					(Requiring 4 or fewer Parking Spaces)								
Vermont	Vermont Agency of Transporatation Access Management Program Guidelines	Not Addressed specifically,but can be assessed from the turning restrictions.	One or both left turn movements at the access may be permitted if the applicant establishes to the Agency's satisfaction that left turn movements would not create unreasonable congestion or safety problems or lower the level of service below Agency Policy.	Not addressed specifically, but can be assessed from the turning restrictions.	One-way	18	24		Posted Speed or Design Speed (mph)	Unsignalized Access Spacing (ft)	With Restrictive Median		
					Two-way *	24	30				Positiion	Access Allowed	Min(ft)
					Two-way **	30	40		20	115	Approaching intersection	Right In/Out	115
									25	155	Approaching intersection	Right In Only	75
					* when the single unit vehicle volume does not exceed				30	200	Departing intersection	Right In/Out	230
					five in peak hour.				35	250	Departing intersection	Right Out Only	100
					** when any one or more of the following apply to the access:				40	305			
									45	360	Without Restrictive Median		
					a. Multi-unit vehicles are intended to use the access.				50	425	Position	Access Allowed	Min(ft)
					b. Single unit vehicles in excess of 30 feet in length will use the				55	495	Approaching intersection	Full Access	230
					access.						Approaching intersection	Right In Only	100
					c. Single unit vehicles volume exceeds 5 in the peak hour.						Departing intersection	Full Access	230
											Departing intersection	Right Out Only	100
Virginia	Road Design Manual 2007	On small corner parcels left turn accessibility may be a problem and access to parcels may be limited to right-in/right-out or similarly restricted movements.Right turn in/outs should accompany reasonable taper, and channelized flow if required	In general,when left-turn volumes are higher than 100 vph, an exclusive left-turn should be considered.Dual left-turn lanes should be considered when left turn hourly volumes exceed 300 VPH.Warrants for left-turn laneson two lane highways provided *(See details in description)*	No rules for full access given specifically, but is addressed under the column of driveway spacings.	Commercial entrances (one-way drive)	16	20	Highway Functional Classification	Legal Speed Limit (mph) (1)	Centerline to Centerline Spacing in Feet			250
					Commercial entrances (two-way drive)	30	40			Unsignalized Intersections & Full Access Entrances (3) / Partial Access Two Way Entrance (4)			
								Urban Principal Arterial (5)	≤ 30	1050 / 270			
									35 to 45	1320 / 325			
									≥ 50	1320 / 510			
								Urban Minor Arterial	≤ 30	660 / 270			
									35 to 45	660 / 325			
									≥ 50	1050 / 510			
								Urban Collector	≤ 30	660 / 200			
									35 to 45	660 / 250			
									≥ 50	1050 / 425			
								Rural Principal Arterial (6)	≤ 30	1320 / 270			
									35 to 45	1320 / 440			
									≥ 50	1760 / 585			
								Rural Minor Arterial	≤ 30	1050 / 270			
									35 to 45	1050 / 440			
									≥ 50	1320 / 585			
								Rural Collector	≤ 30	660 / 270			
									35 to 45	660 / 360			

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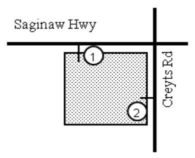
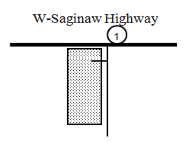
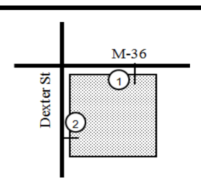
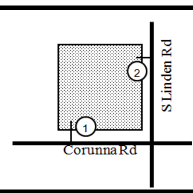
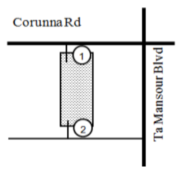
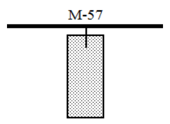
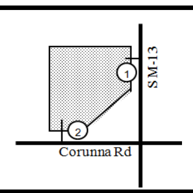
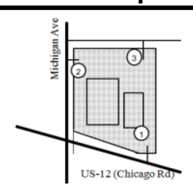
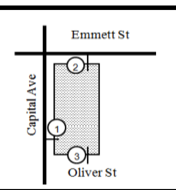
State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection	
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)	
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria	Min Distance(ft)
									≥ 50	1320 495		
								Note: See description for details for values in parenthesis				

Appendix 1. Summary of Turn Restriction Policies

State	Documentation	Rules for Driveway movements			Driveway Width			Driveway Spacing			Corner Clearance at Intersection		
		Restrictive Access		Full Access	Width Criteria	Width of Driveway		Spacing Criteria		Min Driveway Spacing(ft)	(Distance of Driveway from the Intersection)		
		RT-in/out	LT-in/out		Vehicular Volume/Type of Driveway	Min (ft)	Max (ft)	Access Class	Median Type or Speed (mph) or Control		Criteria		Min Distance(ft)
Washington	Design Manual November 2007	All private access connections are for right turns only on multilane facilities, unless there are special conditions and the exception can be justified	Proper channelization should be used to allow Left Turn in/out provided there are special conditions and they are justified to the satisfaction of the department by a traffic analysis	Not addressed specifically, but can be assessed from the turning restrictions				Class		Access Point Spacing (ft) **	With Restrictive Median		
								Class 1		1320	**Position**	**Access Allowed**	**Min (ft)**
								Mobility is the primary function			Approaching Intersection	Right In/Right Out	115
								Class 2		660	Approaching Intersection	Right In Only	75
								Mobility is favored over access			Departing Intersection	Right In/Right Out	230*
								Class 3		330	Departing Intersection	Right In Only	100
								Balance between mobility and access in					
								areas with less than maximum buildout			**Without Restrictive Median**		
								Class 4		250	**Position**	**Access Allowed**	**Min (ft)**
								Balance between mobility and access			Approaching Intersection	Full Access**	230*
								in areas with less than maximum buildout			Approaching Intersection	Right In Only	100
								Class 5		125	Departing Intersection	Full Access	230*
								Access needs may have priority over			Departing Intersection	Right Out Only	100
								mobility					
											* 125 ft may be used for Class 5 facilities with a posted speed of		
								** Minimum, on the same side of the highway.			35 mph or less.		
											** Full Access = All four movements (Right in/out; Left in/out)		
West Virginia	Manual on Rules and Regulations for Constructing Driveways on State Highway Rights-of-Way	Center channelizing island is used in a two-way driveway to restrict entries to right turns in and right turns out	Left turn in/out are allowed after providing certain design conditions, mentioned in description	Not addressed specifically, but can be assessed from the turning restrictions	Driveway Type (Commercial)				Speed Limit (mph)	Spacing (ft)		30 to 50 ft	
					One Way	15	25		25	105			
					Two Way	25	50		30	125			
					(Note: Desirable for Two Way = 30 ft)				35	150			
									40	185			
									45	230			
									50	275			
									55	330			
Wisconsin	Not available online												
Wyoming	WYDOT Access Manual	On multilane urban arterials: If ADT > 30,000 vpd, a median island should be installed. Direct accesses would be right-in/right-out only. Right turn deceleration lanes should be installed at the direct accesses.	A median island would prohibit left turn direct access	Not addressed specifically, but can be assessed from the turning restrictions	Two Way Approach	24	40				From centre of intersection	330ft(min)	

Appendix 2. Description of Sites

Appendix 2. Description of Sites

Site #	Study Site	Type	Schematic Site Layout	Driveway Configuration		Distances (ft)		Posted Speed (mph)		Number of Lanes					
				1	2	Corner Clearance	Distance from Adjacent Driveway	Road Adjacent to Driveway 1	Road Adjacent to Driveway 2	Road Adjacent to Driveway 1			Road Adjacent to Driveway 2		
										LT	Thru	RT	LT	Thru	RT
1	Walgreens driveway, W. Saginaw Highway and Creyts Road, Lansing	Corner		RT in/out only (with channelization)	Full Access (with pavement markings)	243	93	45	N/A	1	2	1	1	1	1
2	MSU FCU driveway, W. Saginaw Highway, Lansing	Mid-block		RT in/out only (with channelization)	N/A	N/A due to midblock	402	55	N/A	1 (TWLT)	2	N/A	N/A	N/A	N/A
3	Rite Aid driveway, SE corner of M-36 and Dexter Road. Brighton	Corner		RT in/out only (with channelization)	Full Access (with pavement markings)	186	96	35	N/A	1	1		1	1	
4	Walgreens driveway, M-21 and Linden Road, Flint	Corner		RT in/out only (with channelization)	Full Access (with no pavement markings)	252	43	45	N/A	1 (TWLT)	2	1	1	2	
5	Krispy Kreme driveway, M-21, Flint	Corner		RT in/out only (with channelization)	Full Access (with pavement markings)	216	336	45	N/A	1	2		N/A	N/A	N/A
6	Tim Hortons driveway, M-57, Clio	Mid-block		RT in/out and LT-in (with channelization)	N/A	N/A due to midblock	92	50	N/A	1 (TWLT)	2	N/A	N/A	N/A	N/A
7	BP gas station and fast food restaurants, M-21, Lennon	Corner		RT in/out only (with channelization)	Full Access (with no pavement markings)	291	61	55	N/A	1		1	1	2	1
8	National City Bank and Advance Auto, NE Quadrant of US-12 (Chicago Road) and Michigan Avenue, Coldwater	Corner		RT-in only (with channelization)	Full Access (with no pavement markings)	242	42	35	N/A	1	2		1	1	
9	Family Video driveway, SE corner of M-66 (Capital Ave) and Emmett Street, Battle Creek	Corner		RT-in only (with channelization)	Full Access (with no pavement markings)	201	54	25	N/A	1	1		1	2	

Appendix 3. Manual Data Collection Forms

FIELD DATA WORKSHEET FOR TRAFFIC VOLUMES

General Information

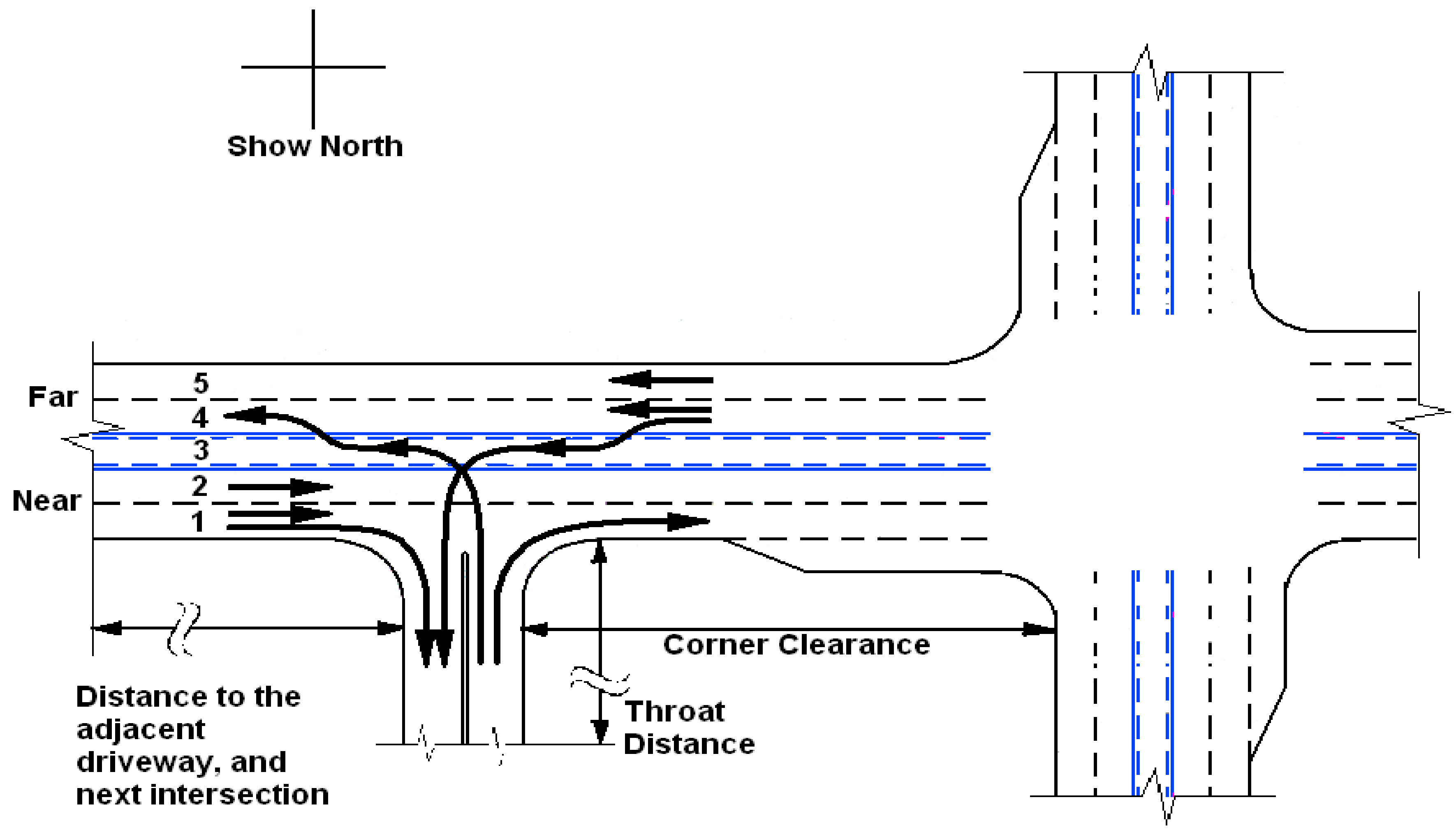
Site/Location ____

Date (mm/dd/yy) ____________________ ____________________

Name of Person Collecting Data ____________________ Analysis Time Period ____________________

Type of Driveway Control
☐ Non-Restricted
☐ Restricted : ○ RT In/Out Only ○ RT In/Out + LT In ○ RT In/Out + LT Out

Driveway Geometry



Traffic Volumes

Time Period	Time Interval (15min)	Volume								No of Vehicles in Queue during counting intervals		
		Near				Far						
		Direction:________________				Direction:________________						
		Thru(2)	Thru(1)	RT-in(1)	RT-out(1)	Thru(5)	Thru(4)	LT-in(4)	LT-out(4)	LT-Lane(3)	Lane(2)	Lane(1)
1												
2												
3												
4												
5												
6												
7												
8												

General Observations/Notes:

____
____
____
____
____
____
____

Abbreviations used in the Table

Thru(2)	Through traffic in lane 2
Thru(1)	Through traffic in lane 1
RT-in(1)	Right turning traffic from lane 1 into driveway
RT-out(1)	Right turning traffic from driveway into lane 1
Thru(5)	Through traffic in lane 5
Thru(4)	Through traffic in lane 4
LT-in(4)	Left turning traffic from lane 4 into driveway
LT-out(4)	Left turning traffic from driveway into lane 4

TRAVEL TIME DATA COLLECTION FORM

NAME OF THE OBSERVER: ______________________________ **NAME OF THE STREET:** ____________________________________

DATE: ______________________ **TIME:** ________________ **WEATHER:** ____

RUN NUMBER	DIRECTION	*START TIME	INTERMEDIATE STOPS						*END TIME
			START TIME	END TIME	START TIME	END TIME	START TIME	END TIME	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

* Time between starting and ending point

Appendix 4. Crash Data Summary for All Sites

Appendix 4. Crash Data Summary for All Sites							
Volume Category	**Site number**	**ADT (vpd)**	**Type of control**	**Corner Clearance (ft)**	**Number of driveway-related crashes**		**Remarks**
					Before	**After**	
Corner Sites							
High Volume*	Site 1	33,200	Right-in/Right-out	209	3 in 4 years	None in 4 years	reduction in driveway-related crashes after restricting the driveway to right turns only
	Control Site 1	19,857	Full access	170	9 in 8 years, before and after periods not clear (probably no change)		driveway-related crashes have been observed almost every year 2000-2007 involving left turning movements
	Site 4	18,400	Right-in/Right-out	224	5 in 3 years	1 in 5 years	reduction in driveway-related crashes after restricting the driveway to right turns only
	Control Site 4	20,800	Full access	150	5 in 8 years, before and after periods not clear (probably no change)		driveway-related crashes have been observed from 2000-2007 involving left turning movements
	Site 5	27,200	Right-in/Right-out	182	none in 4 years	1 in 4 years	only crash was due to left turning violation; effect of turning restriction not clear
	Control Site 5	27,200	Full access	185	3 in 8 years (site was not changed since at least 2001)		all 3 driveway-related crashes involved left turning movements
	Site 9	14,800	Right-in only	224	3in 5 years	none in 2 years	reduction in driveway-related crashes after restricting the driveway to right turns only
	Control Site 9	15,083	Full access	150	4 in 8 years, before and after periods not clear (probably no change)		driveway-related crashes have been observed at this site from 2000-2007 involving left turning movements
	Site 8	17,170	Right-in only	252	no clear information found		due to proximity of next development, no clear information was found regarding whether the driveway-related crashes were related to this driveway or the one next to it
	Control Site 8	9648 (medium volume)	Full access	275	3 in 8 years-before and after periods not clear (probably no change)		in spite of not having high traffic volume, left-turning movements were found to be involved in all the driveway-related crashes

Appendix 4. Crash Data Summary for All Sites							
Volume Category	**Site number**	**ADT (vpd)**	**Type of control**	**Corner Clearance (ft)**	**Number of driveway-related crashes**		**Remarks**
					Before	**After**	
Corner Sites (continued)							
Low to Medium Volume	Site 3	11,210	Right-in/right-out	256	1 in 3 years	none in 4 years	the only crash that occurred before the site was changed involved left turning movement.low crash frequency in general, effect of turning restriction not clear
	Control Site 3	5,390	Full access	200	none in 8 years		no crashes during entire period at this low-volume site
	Site 7	4,480	Right-in/Right-out	229	none in 4 years	none in 4 years	no crashes during entire period at this low-volume site; suggests that turning restrictions not necessary
	Control Site7	11,893	Full access	100	12 in 8 years (site was not changes since 2001 but could be there even before that)		high number of driveway-related crashes at full-access driveway, mostly involving left-out movements; very low corner clearance may also have an effect
Mid-Block Sites							
High Volume	Site 2	28,100	Right-in/Right-out	N/A	none in 8 years		low crash frequency in general, effect of turning restriction not clear
	Control Site 2	17,100	Full access	N/A	3 in 8 years, before and after periods not clear (probably no change)		driveway-related crashes have been observed at this mid-block site from 2000-2007 involving left turning movements
	Site 6	38,140	Right-in/Right-out/Left-in	N/A	none in 8 years		no driveway -related crash was found, effect of turning restriction not clear
	Control Site 6	38,140	Right-in/Right-out	N/A	1 in 8 years, before and after periods not clear (probably no change)		the only crash that occurred at this restricted driveway was caused by left-turning violation

* high volume = ADT>15,000vpd

Appendix 5. Additional Results for Model 1

Average delay (sec/veh) for LT-in traffic for different turning volumes (CC=250ft)

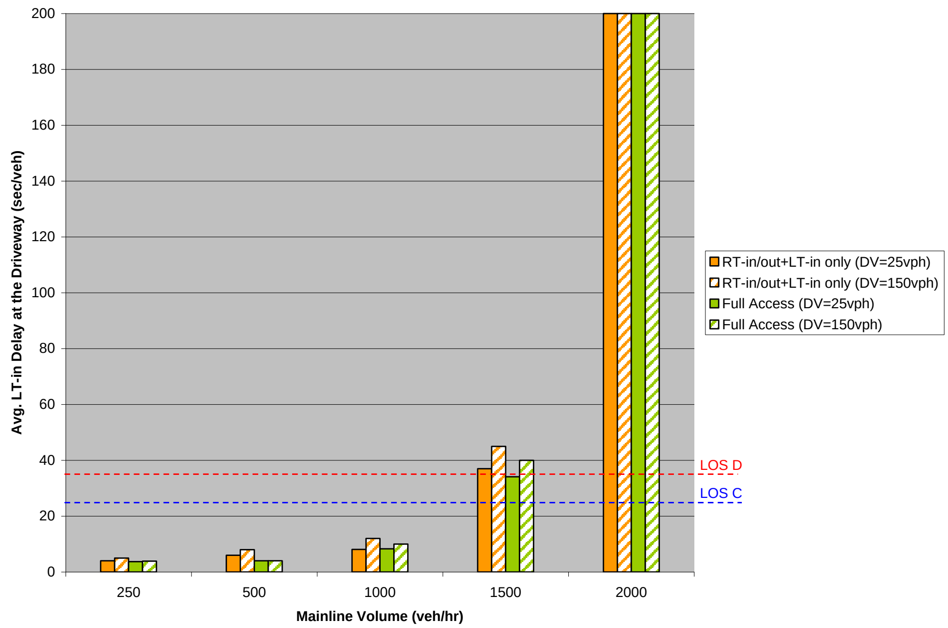


Figure 5-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

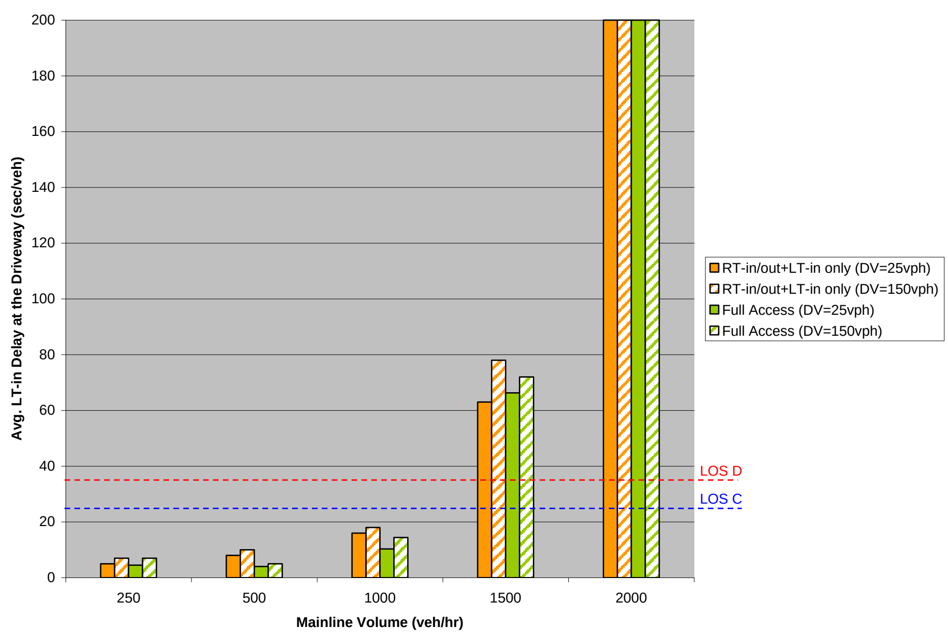


Figure 5-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

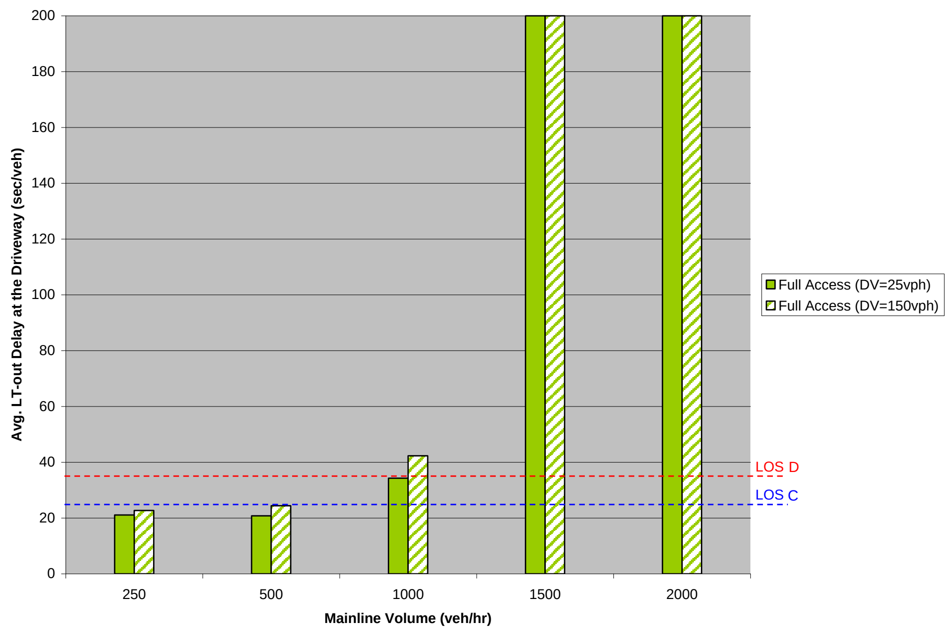


Figure 5-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

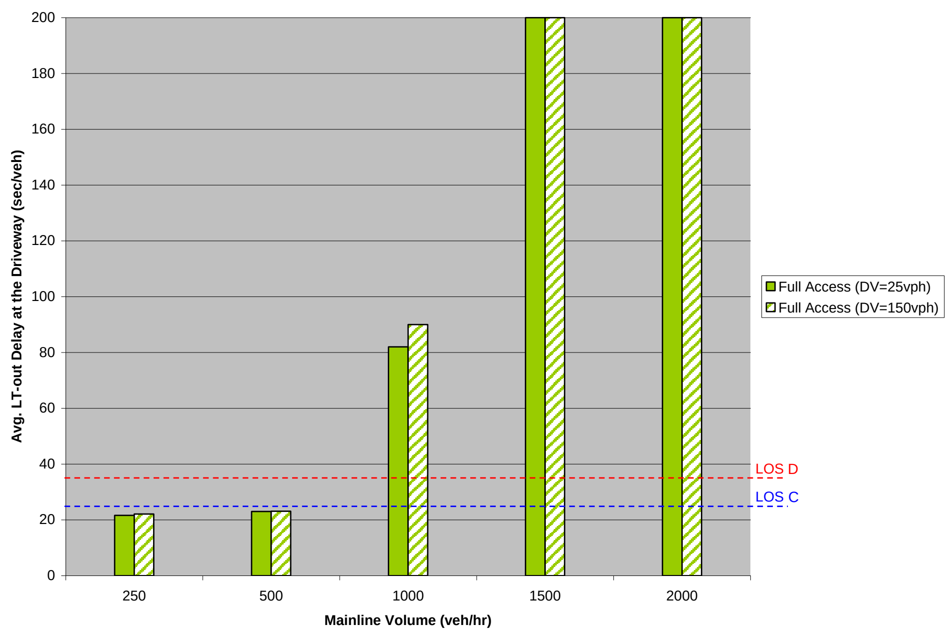


Figure 5-4. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for LT-in traffic for different turning volumes (CC=350ft)

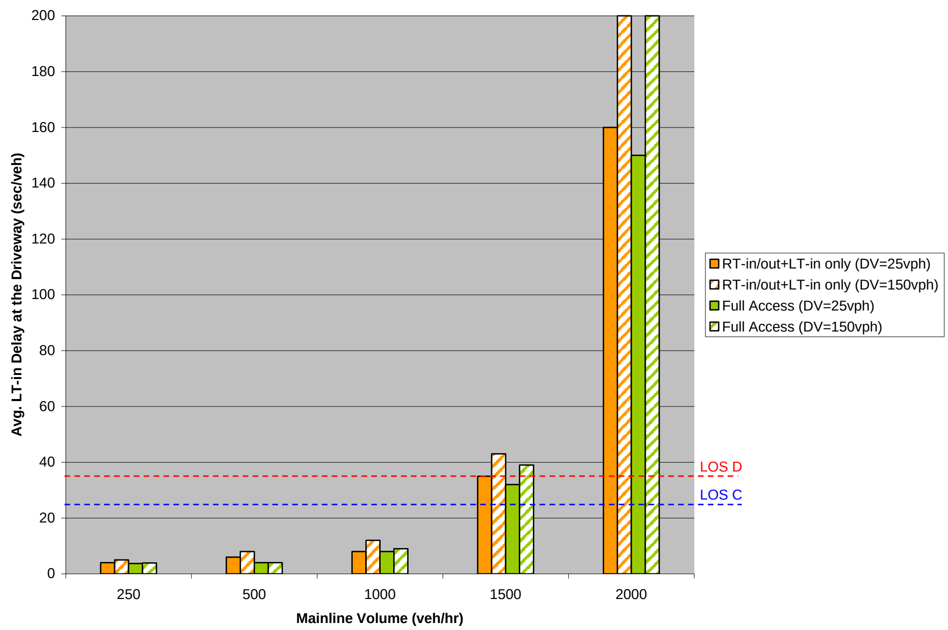


Figure 5-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

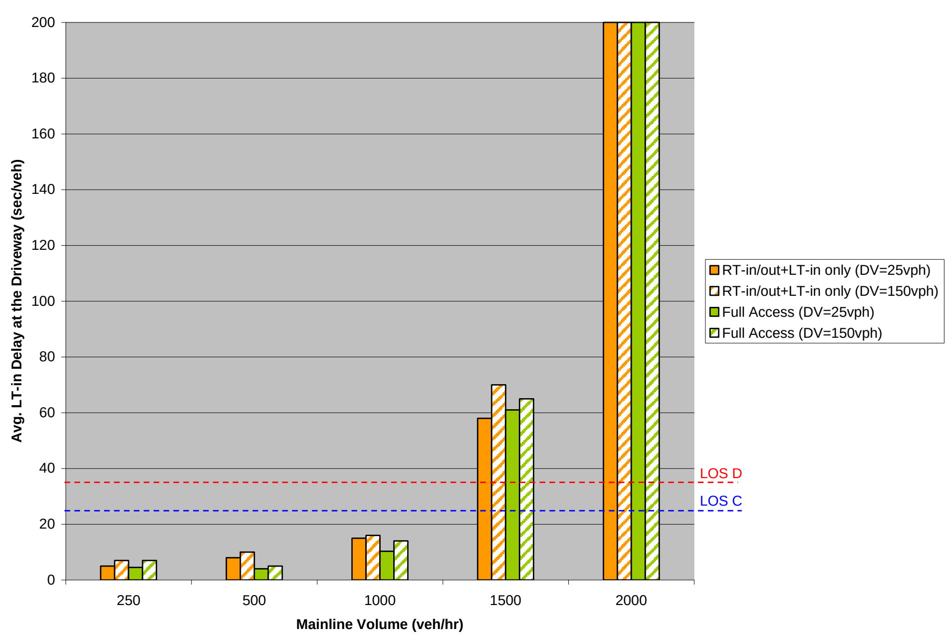


Figure 5-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=350ft)

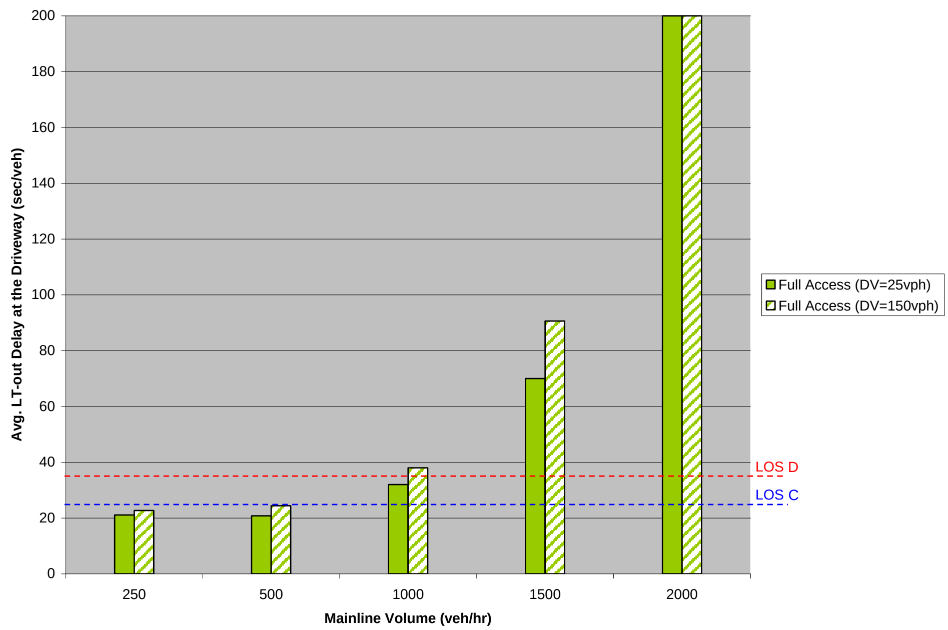


Figure5-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

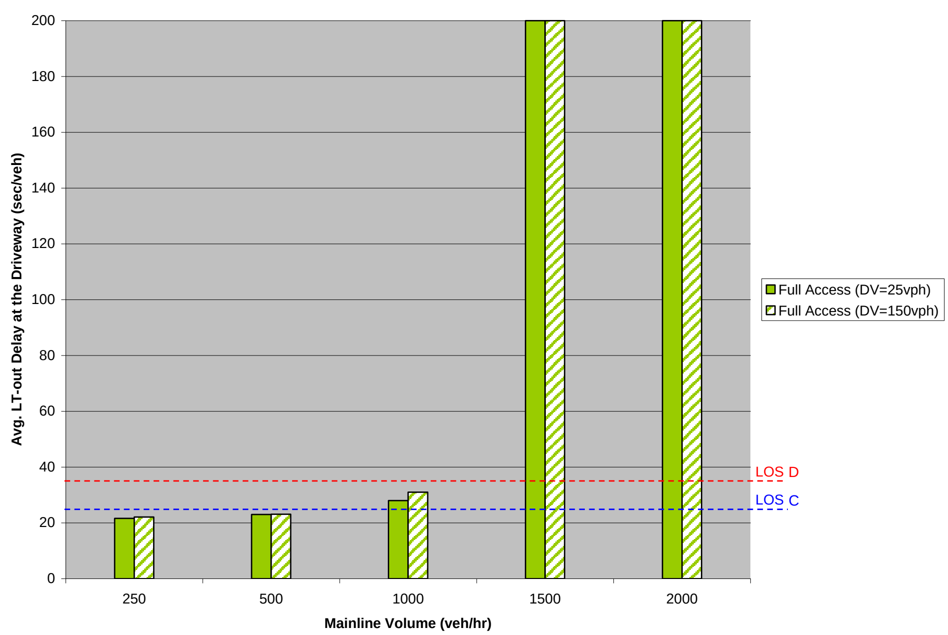


Figure 5-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Appendix 6. Results for Model 2

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

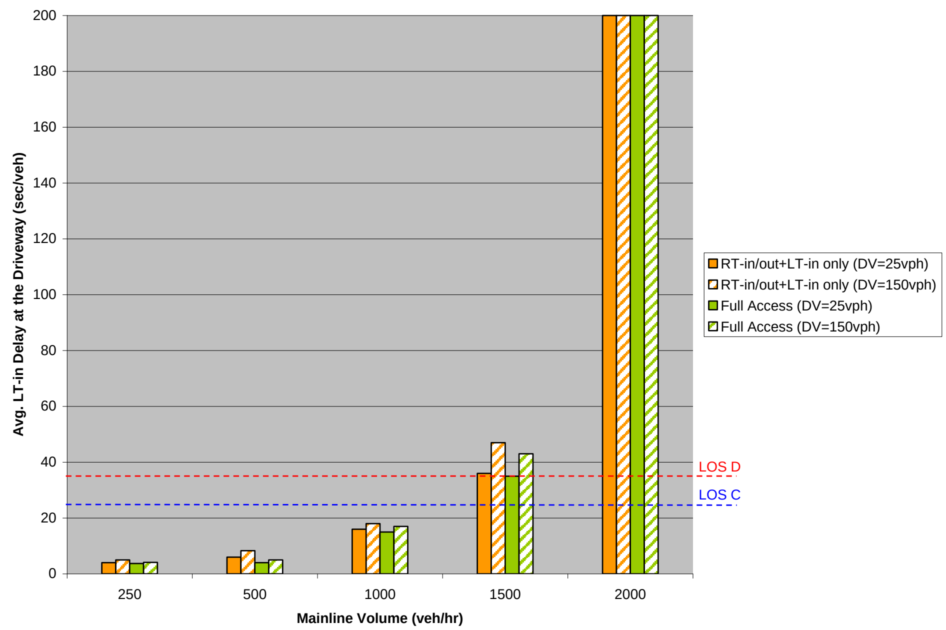


Figure 6-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

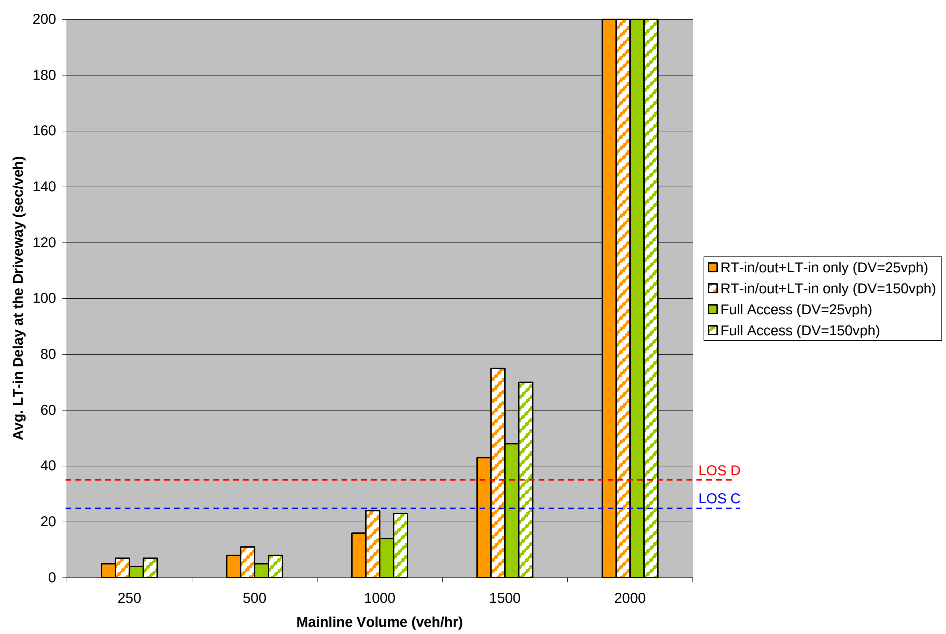


Figure 6-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

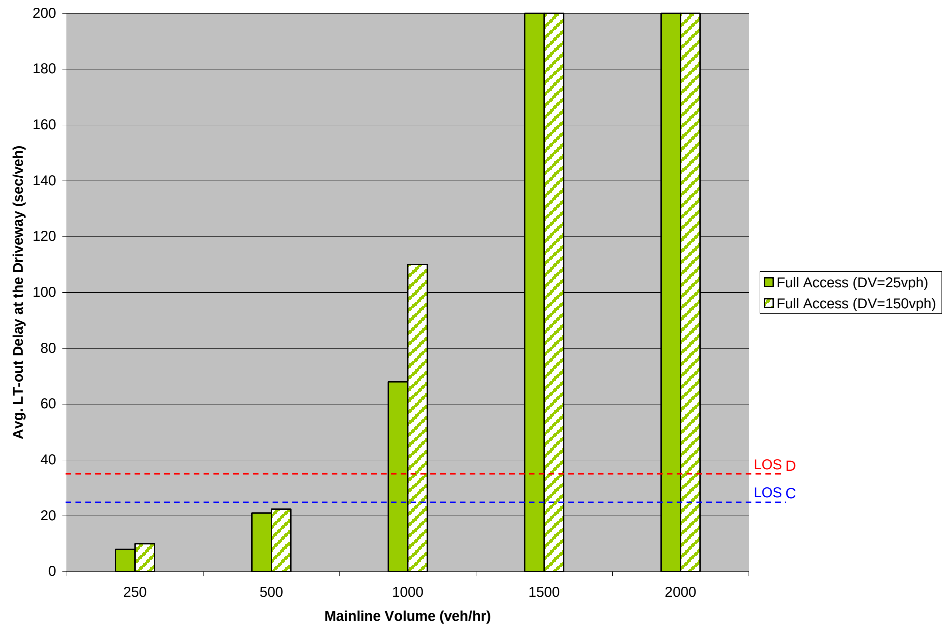


Figure 6-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

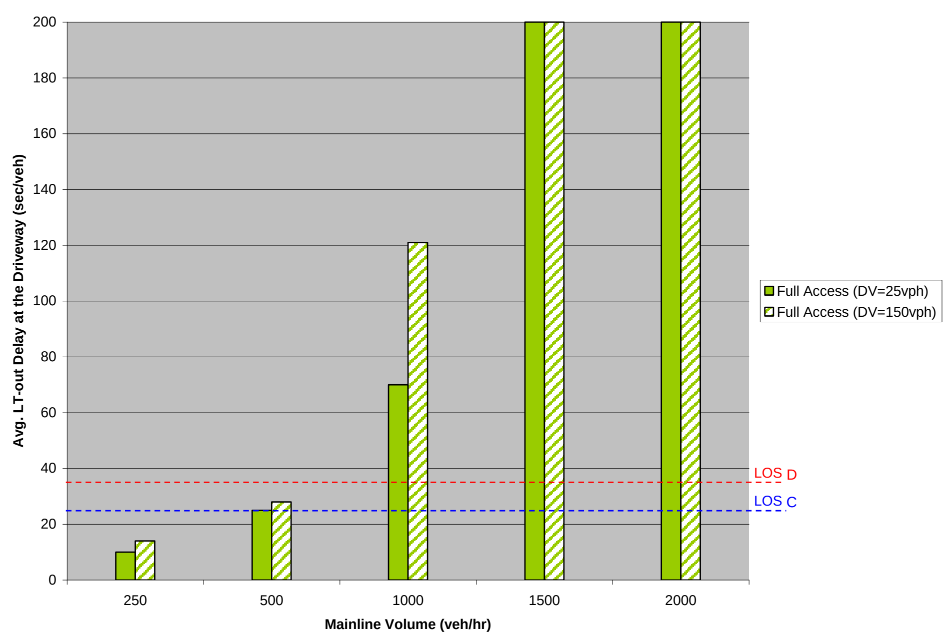


Figure 6-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=250ft)

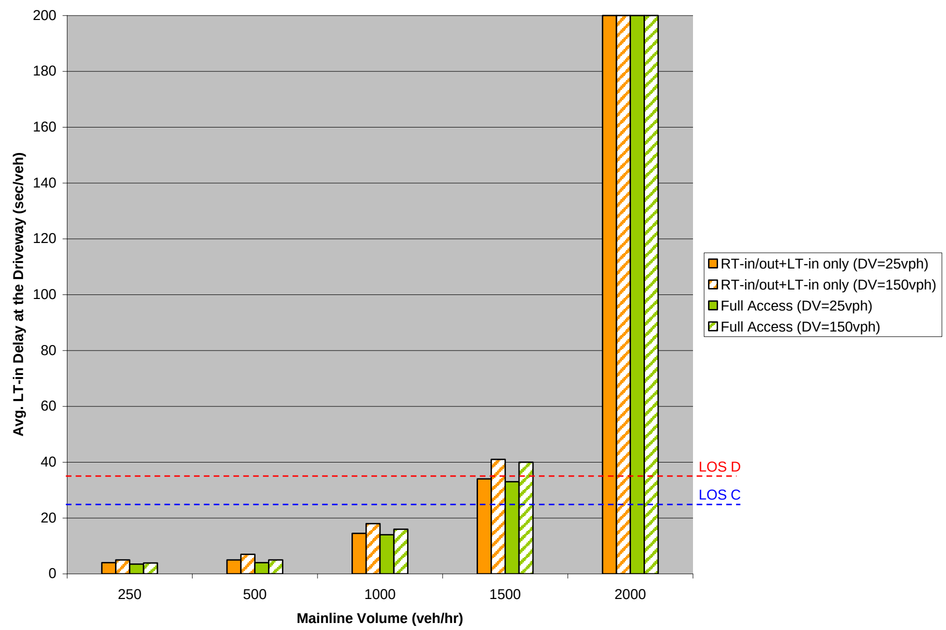


Figure 6-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

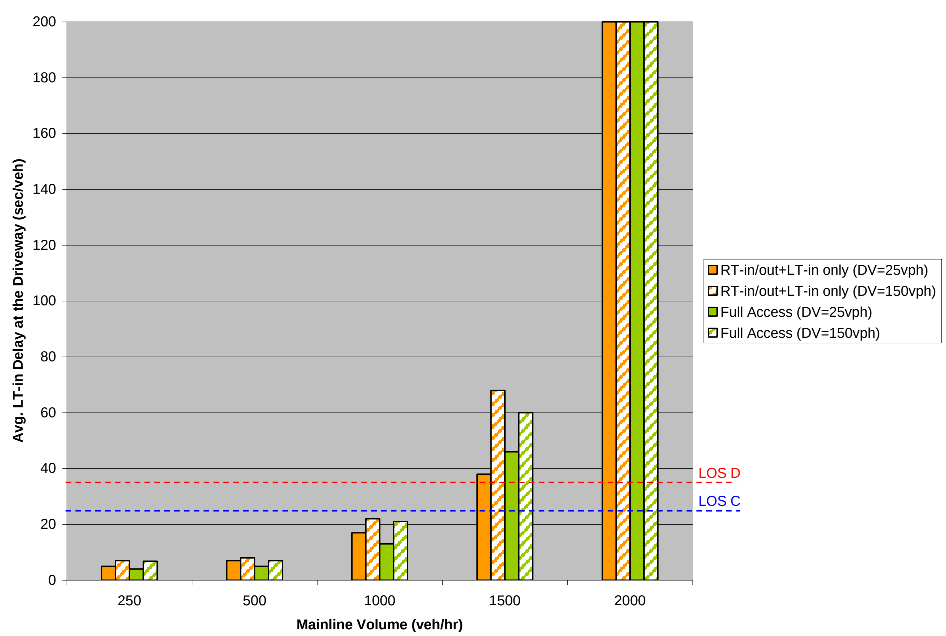


Figure 6-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

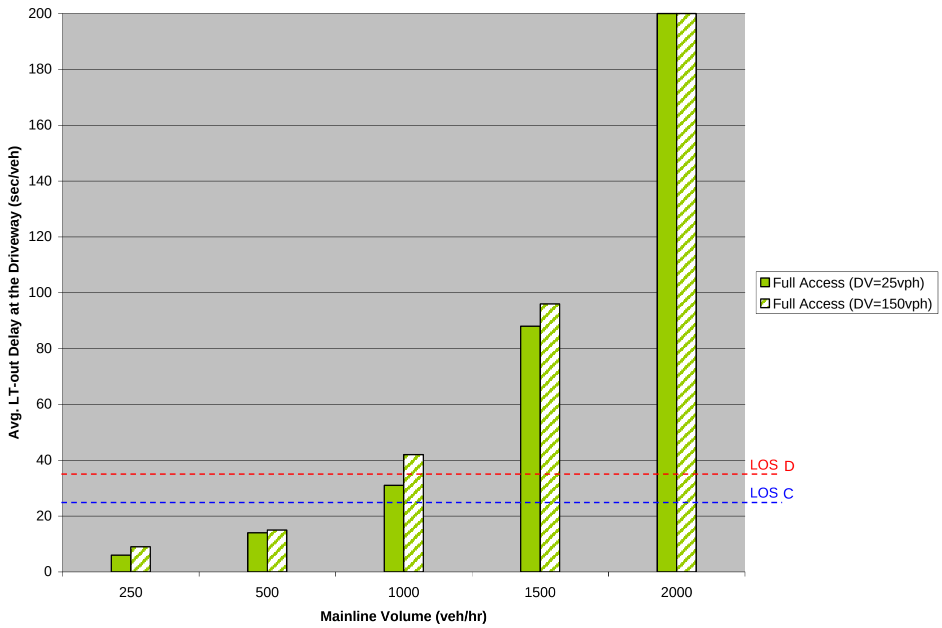


Figure 6-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

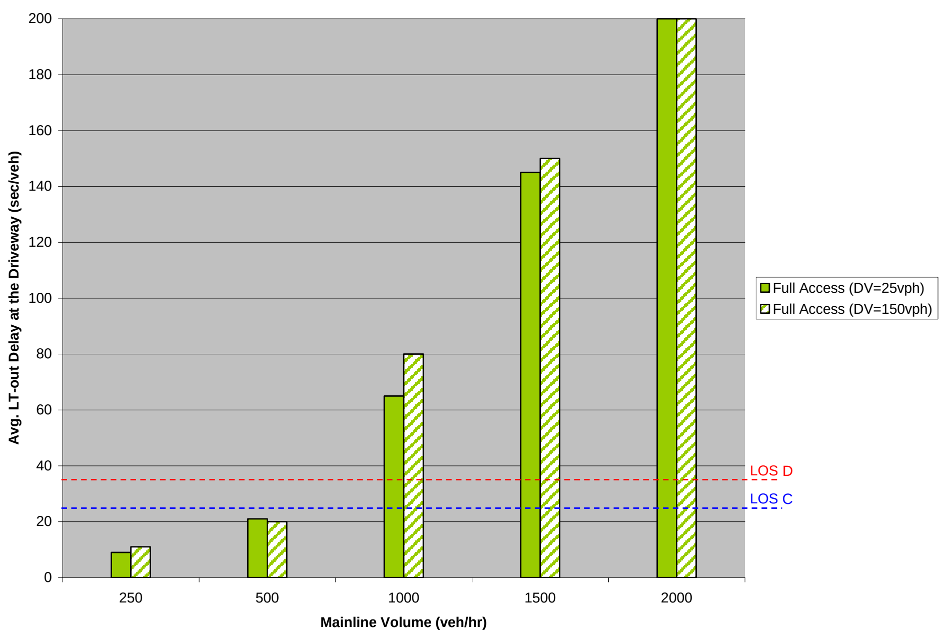


Figure 6-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=350ft)

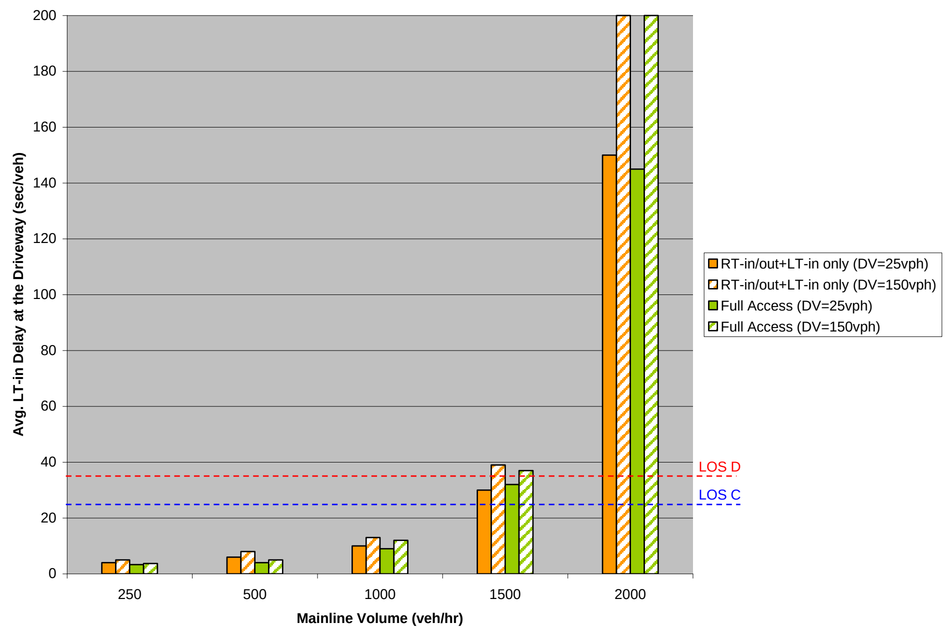


Figure 6-9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

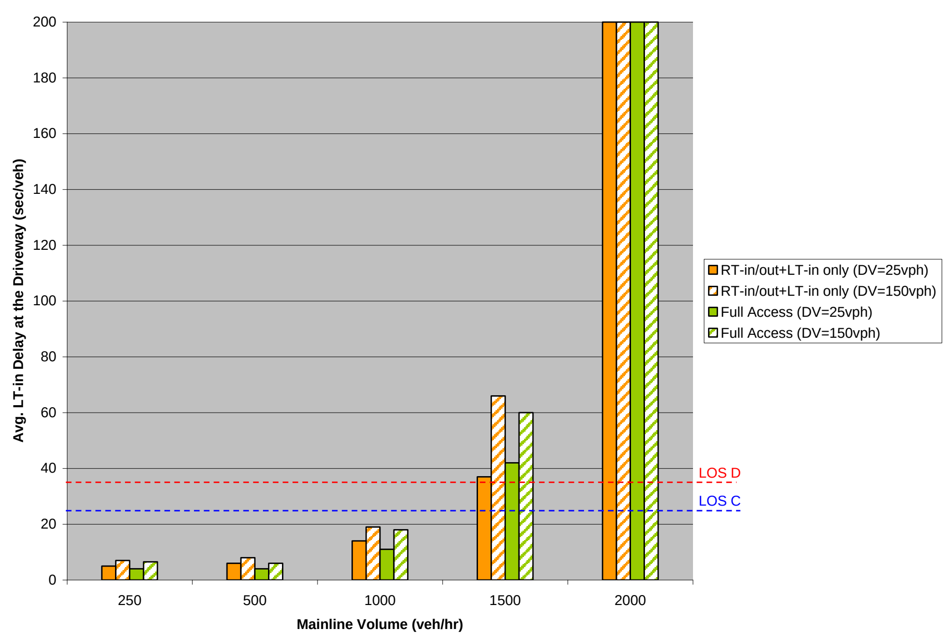


Figure 6-10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for _LT-out traffic_ for different turning volumes (CC=350ft)

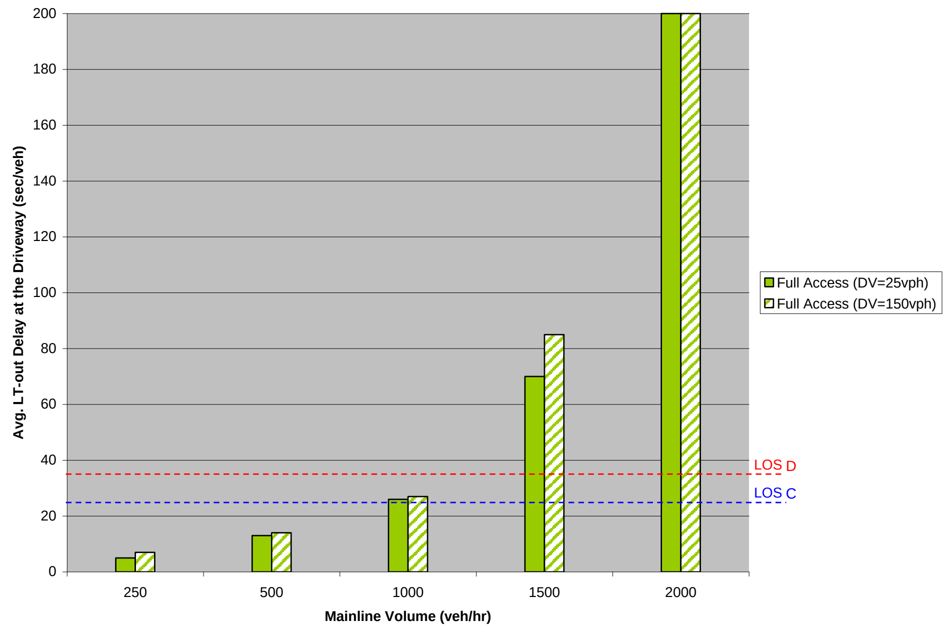


Figure 6-11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

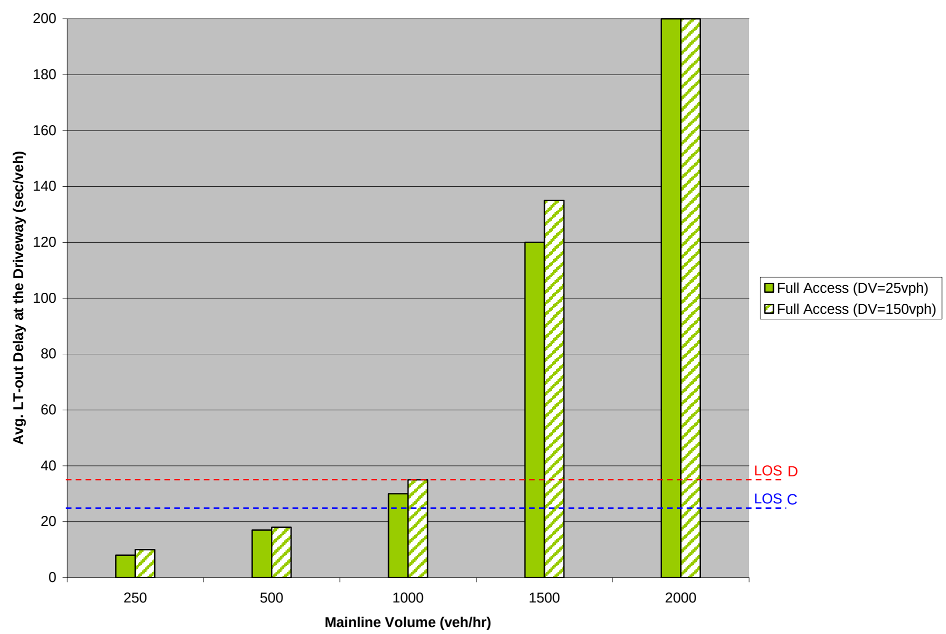


Figure 6-12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

50th Percentile Queue Length (ft)

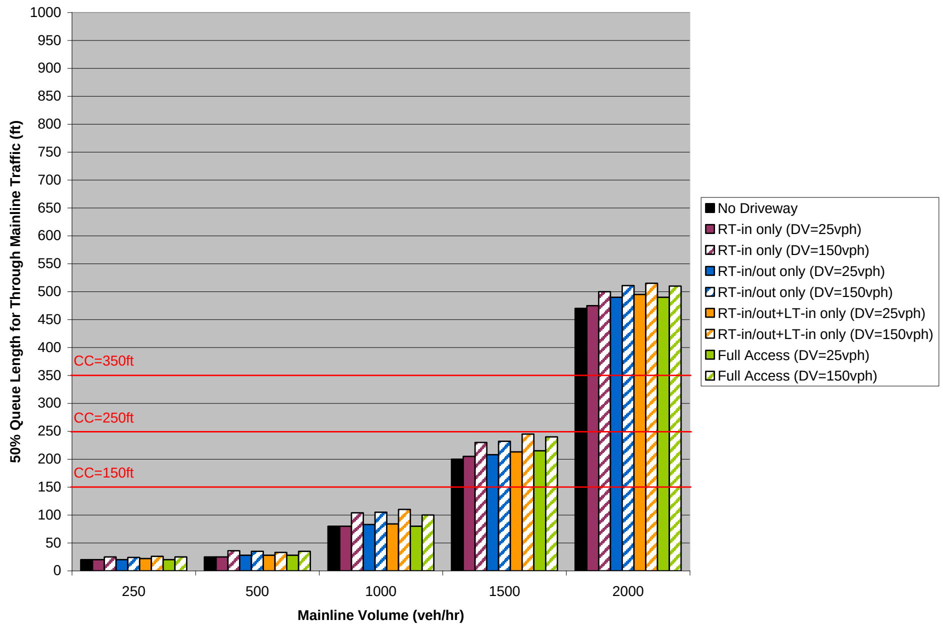


Figure 6-13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

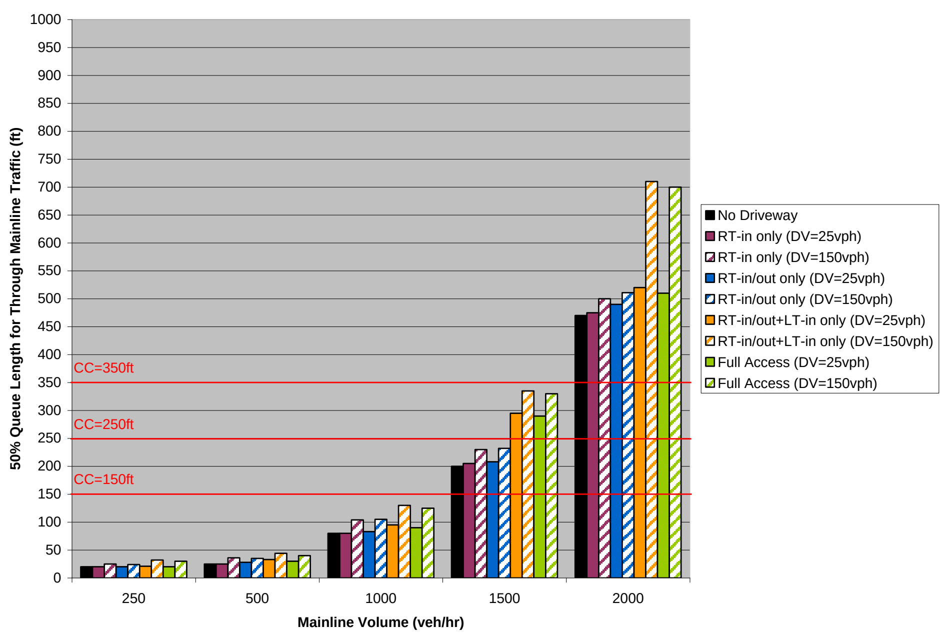


Figure 6-14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Appendix 7. Results for Model 3

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

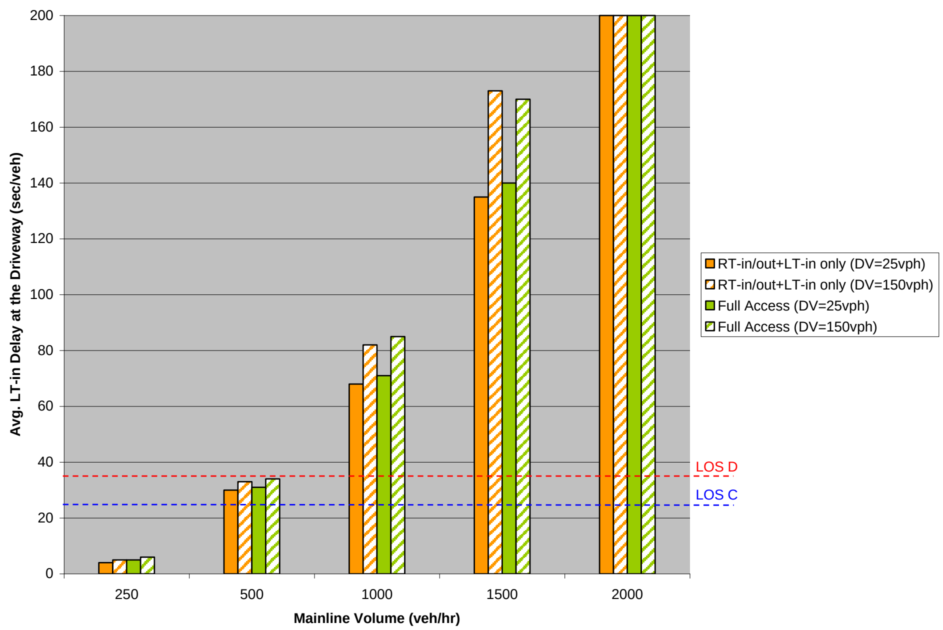


Figure 7-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

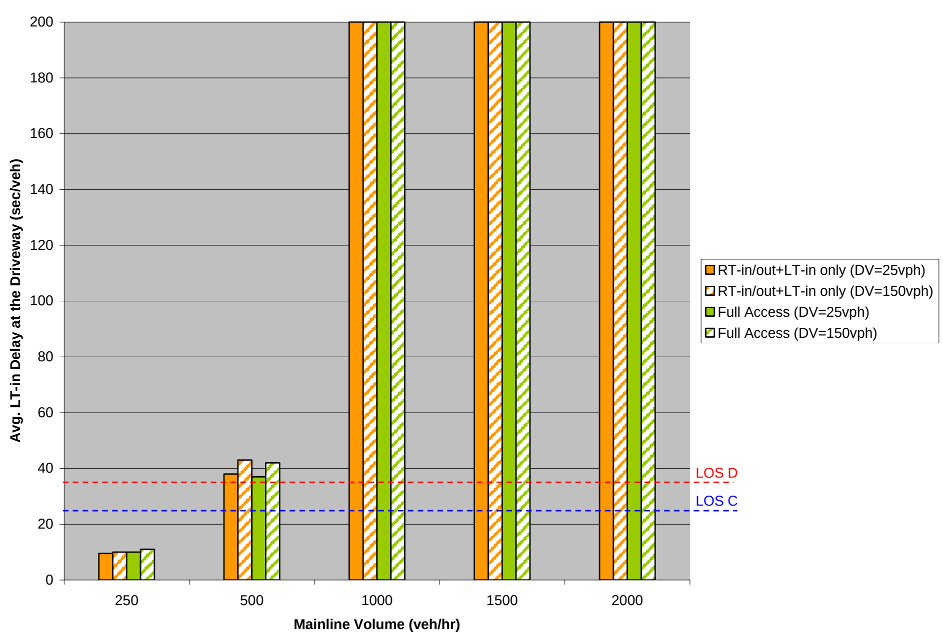


Figure 7-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

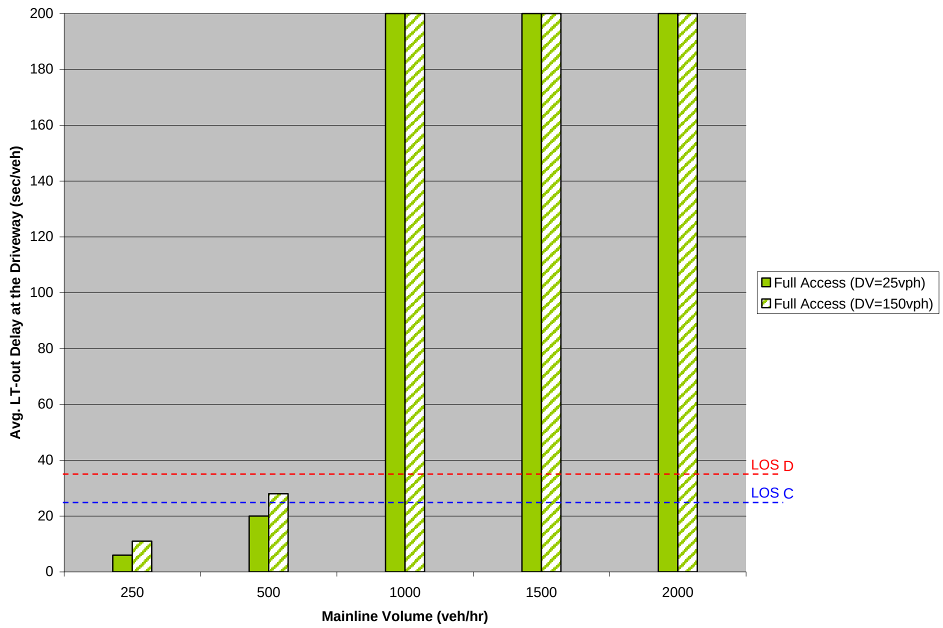


Figure 7-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

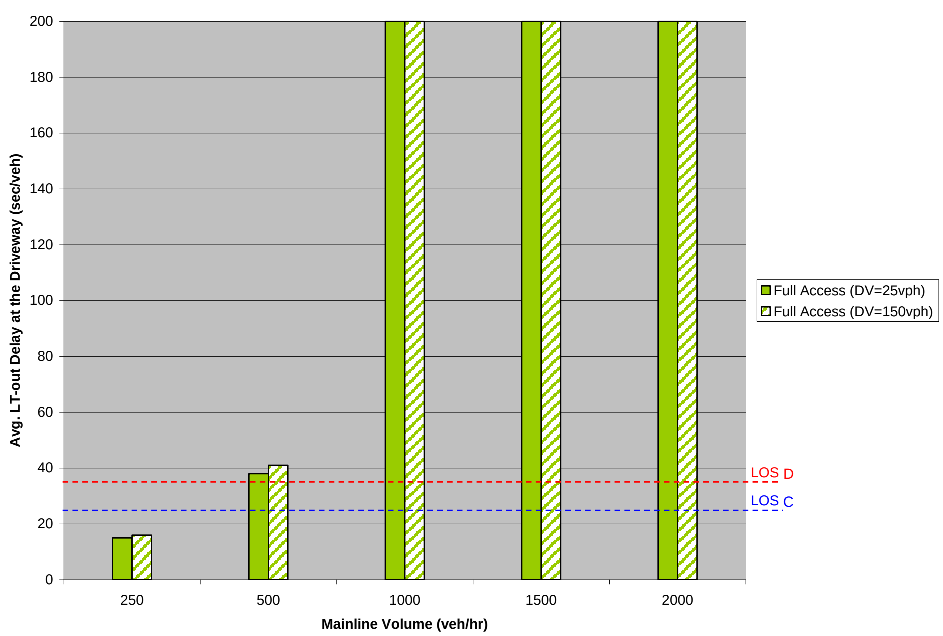


Figure 7-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=250ft)

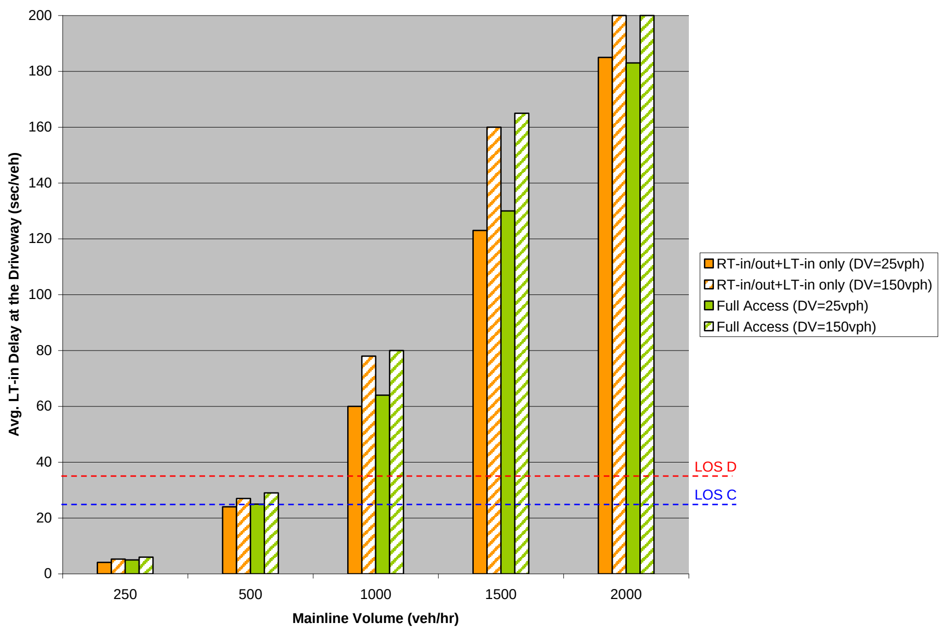


Figure 7-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

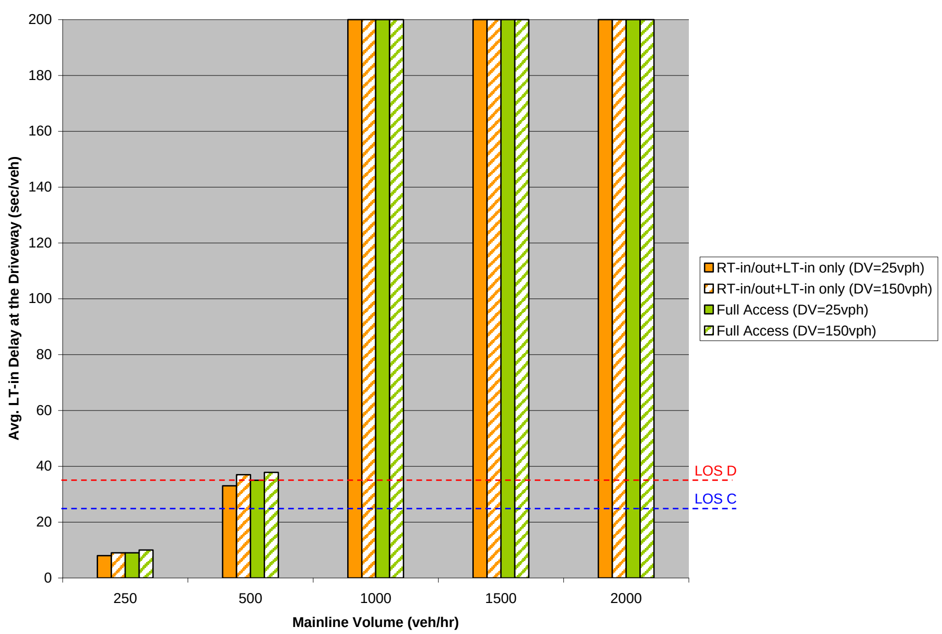


Figure 7-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

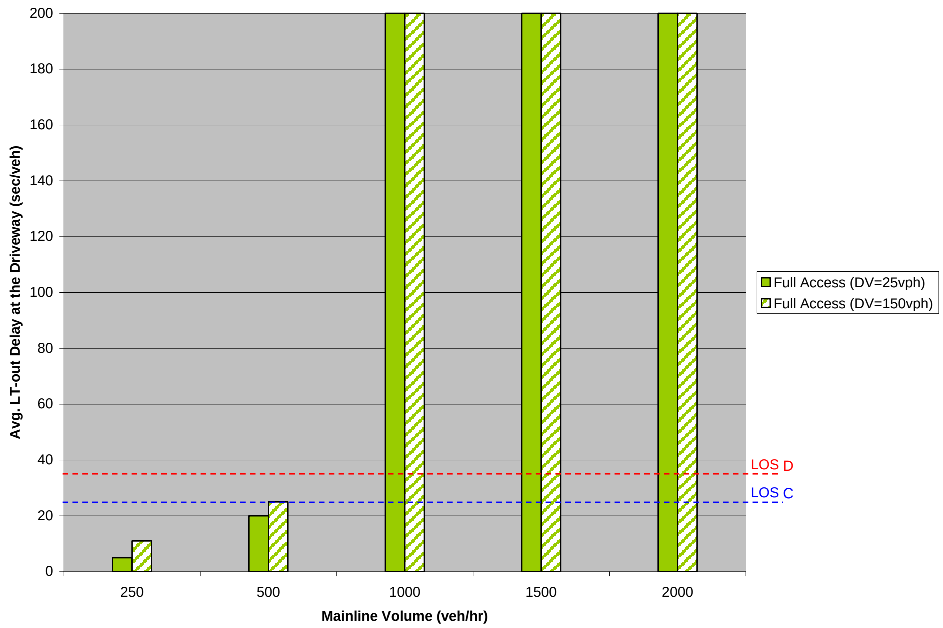


Figure 7-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

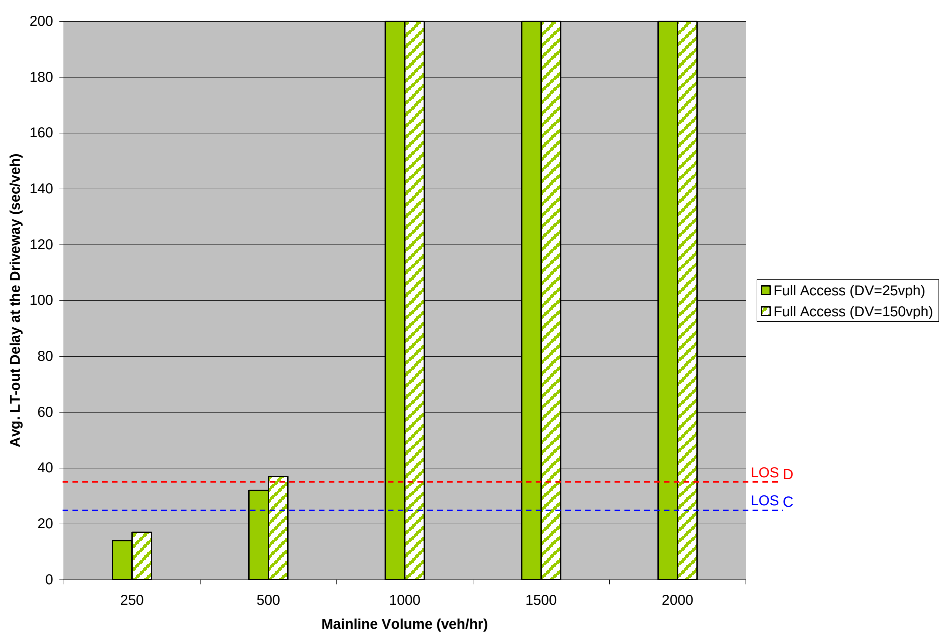


Figure 7-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=350ft)

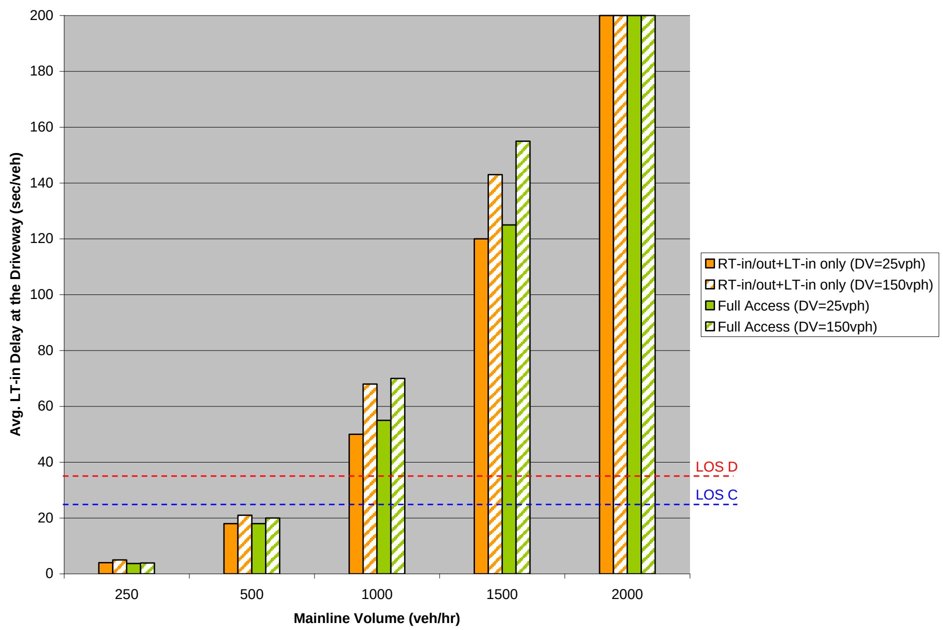


Figure 7-9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

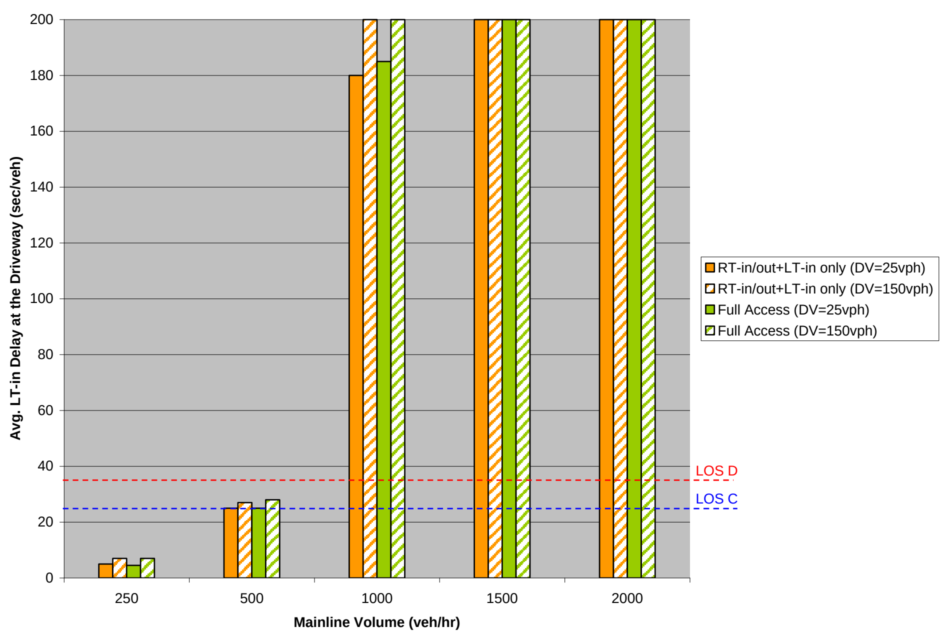


Figure 7-10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=350ft)

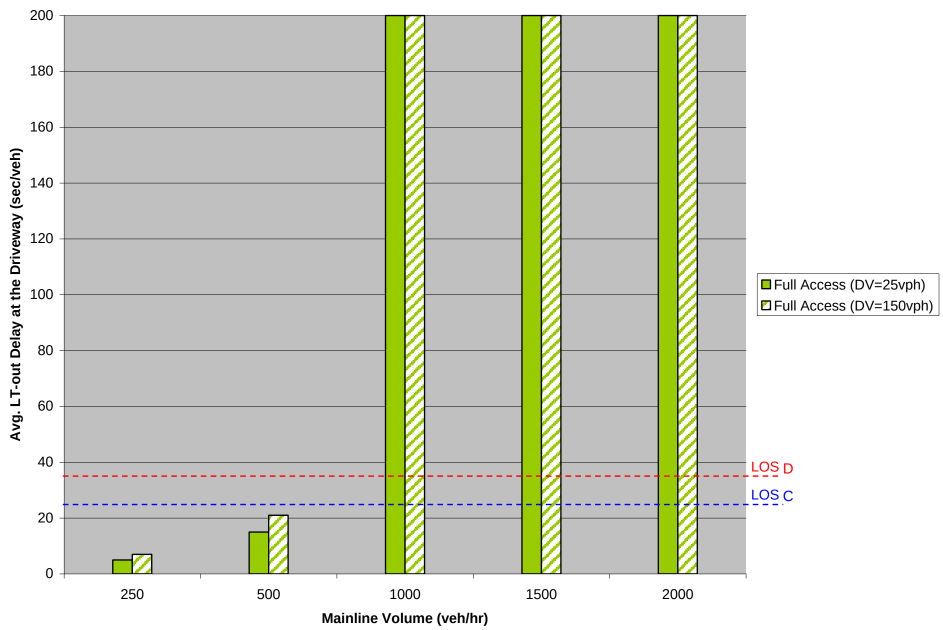


Figure 7-11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

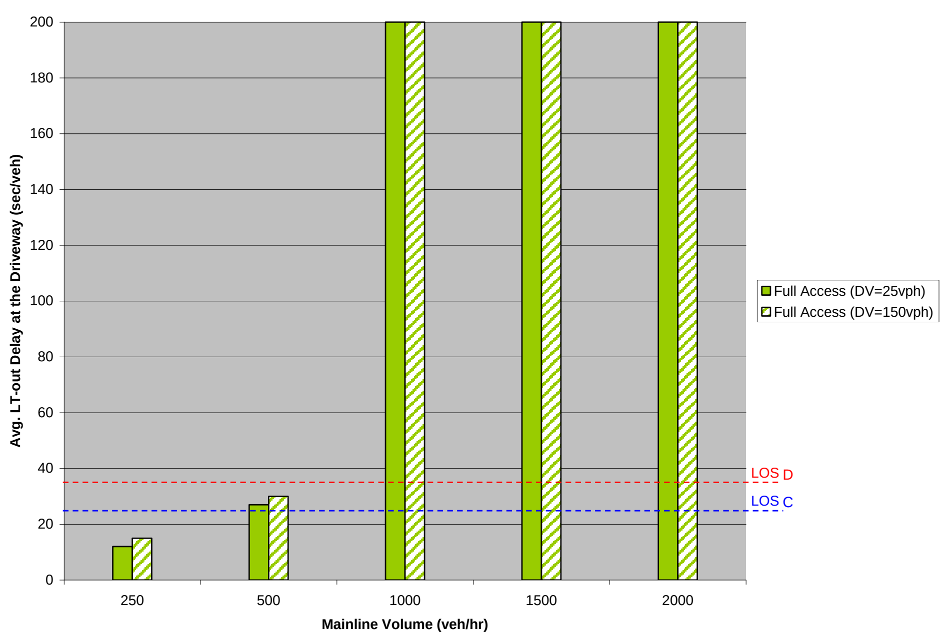


Figure 7-12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

50th Percentile Queue Length (ft)

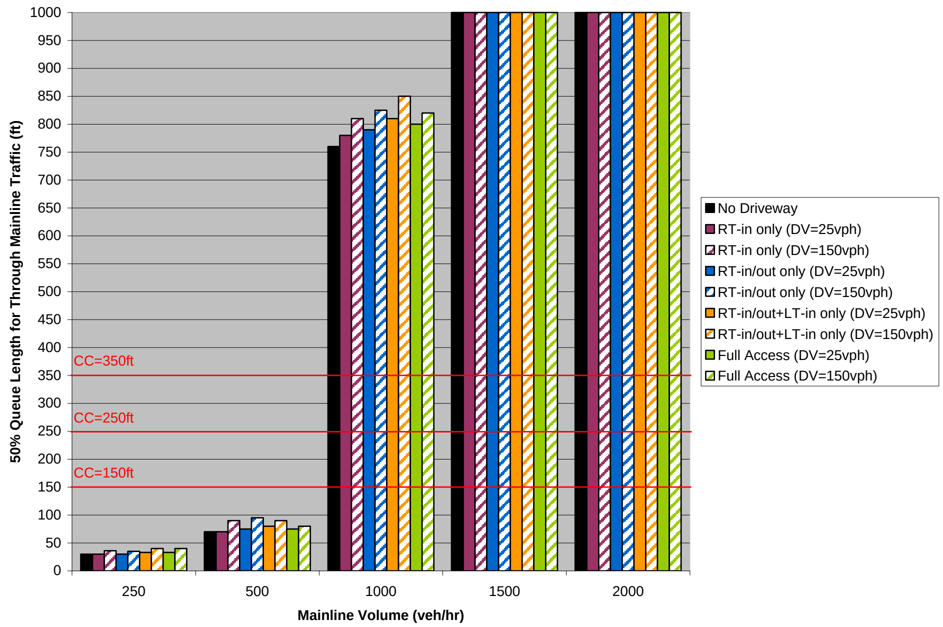


Figure 7-13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

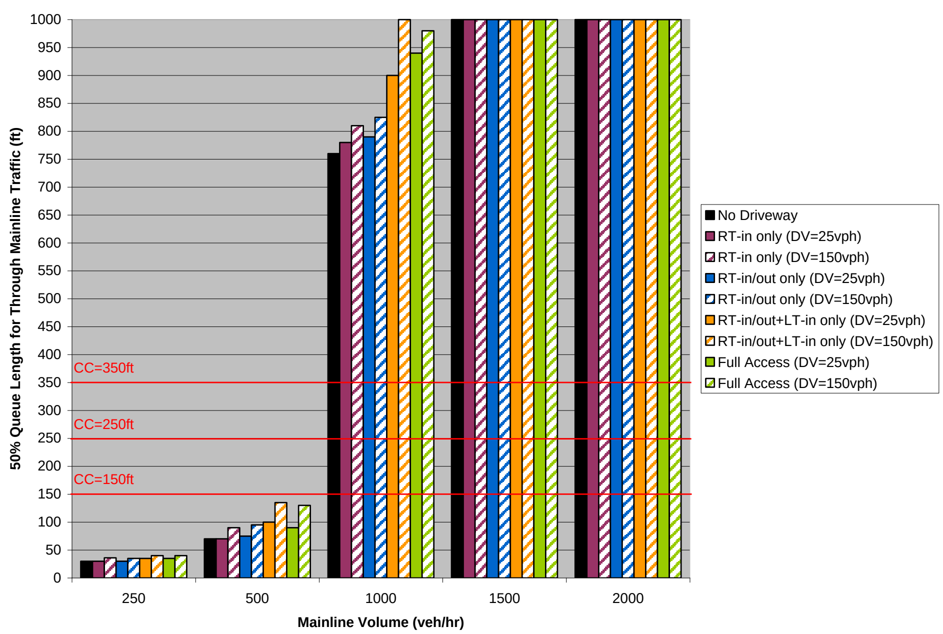


Figure 7-14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Appendix 8. Results for Model 4

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

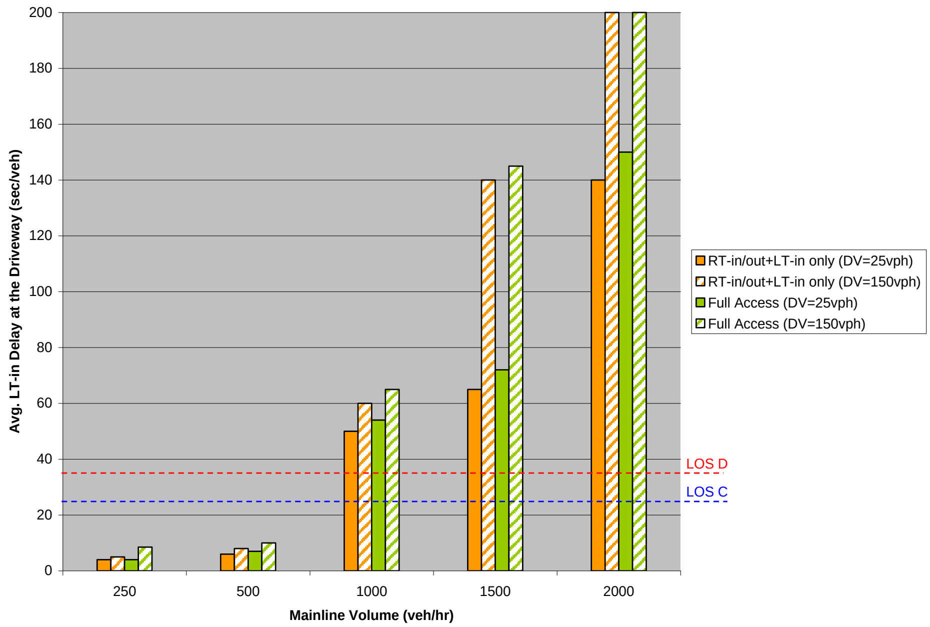


Figure 8-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

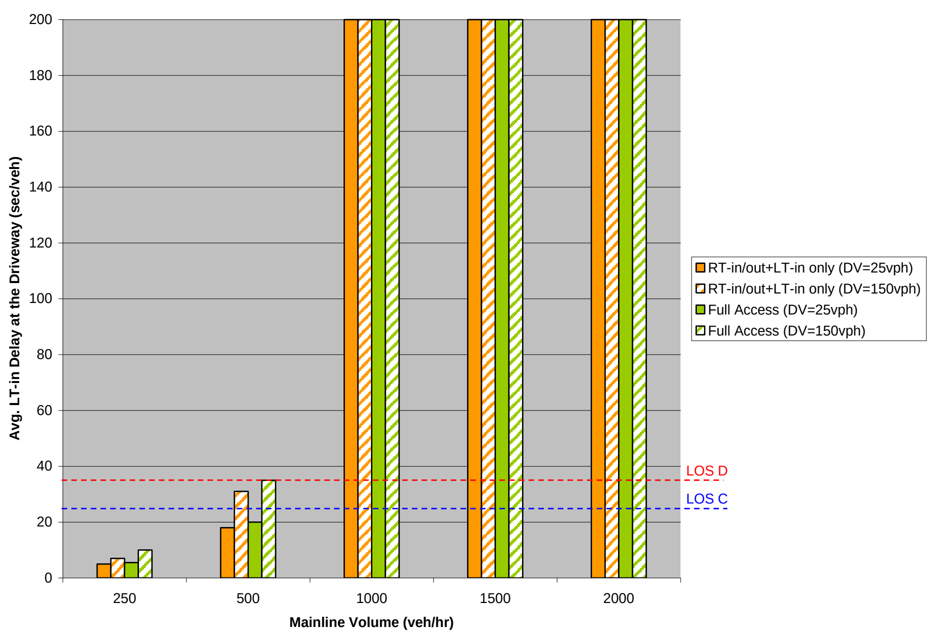


Figure 8-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

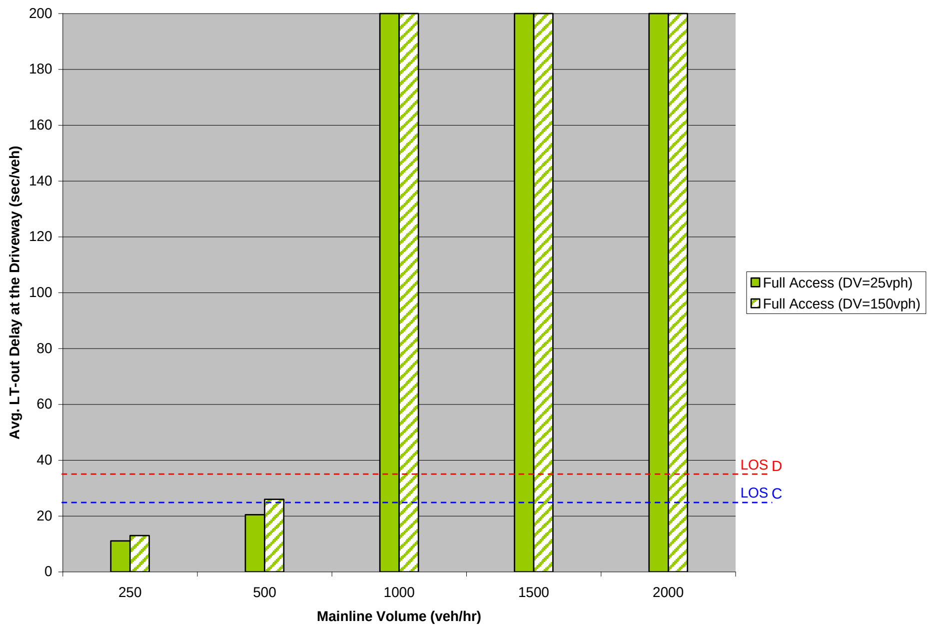


Figure 8-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

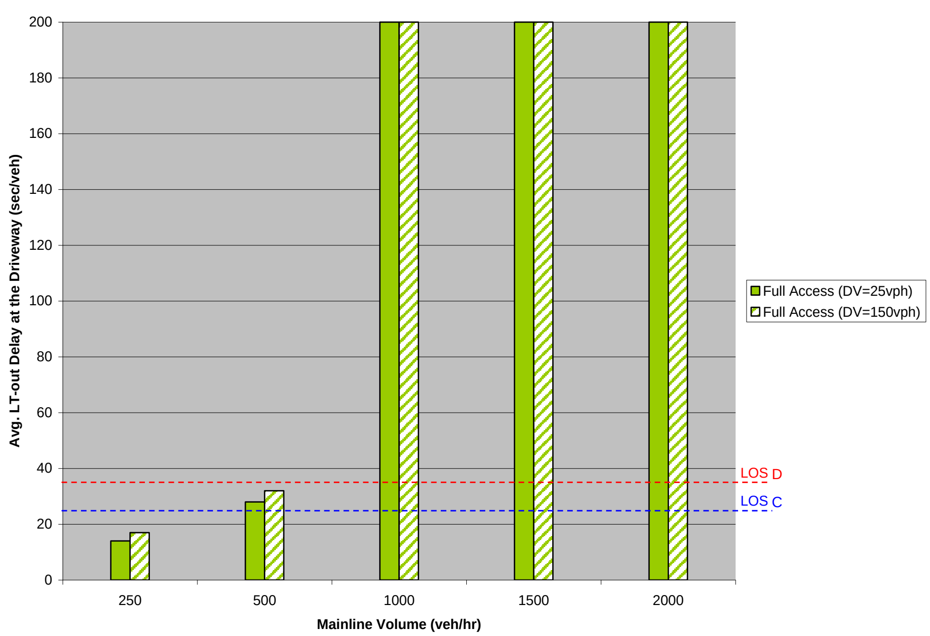


Figure 8-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=250ft)

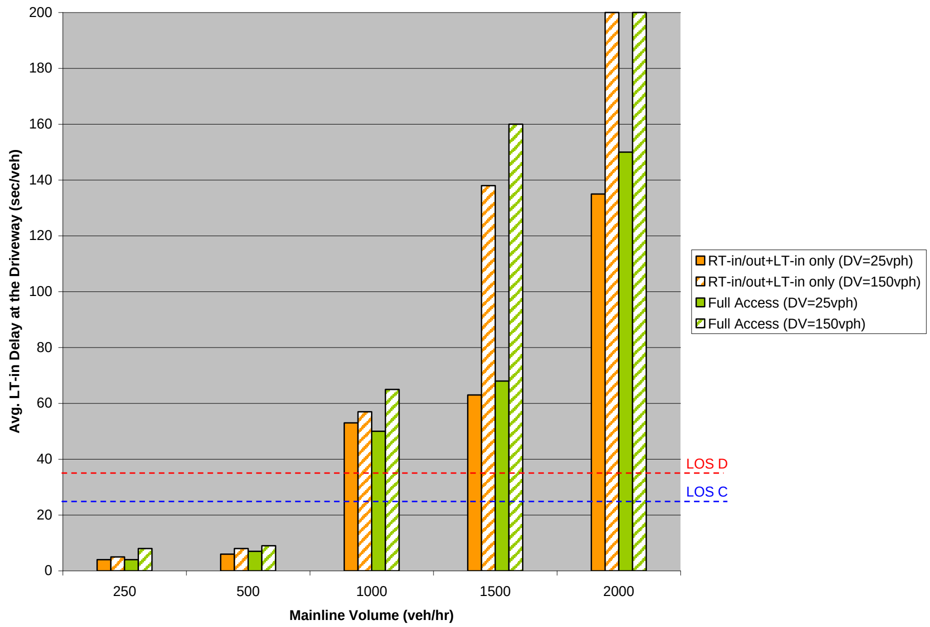


Figure 8-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

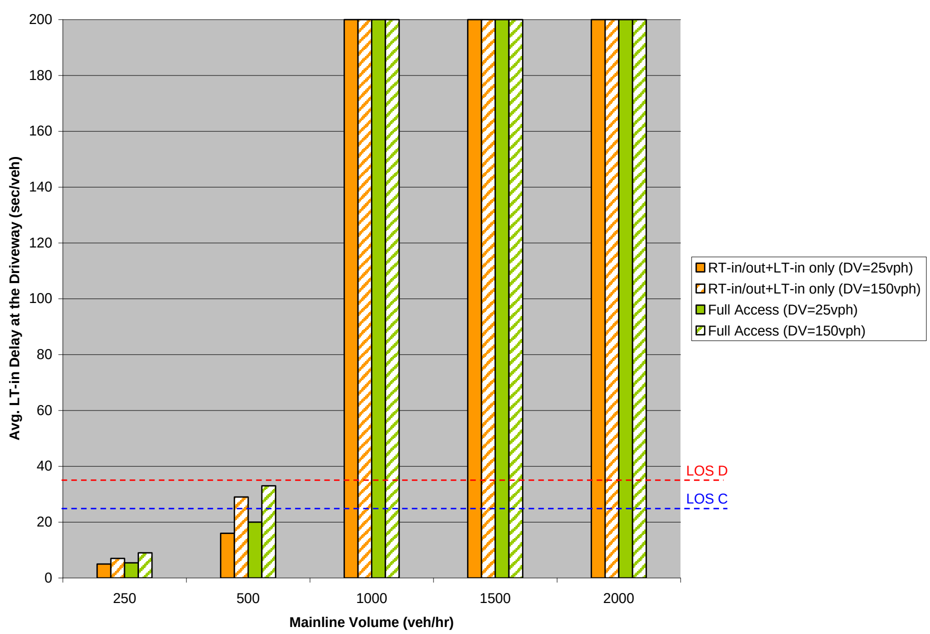


Figure 8-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

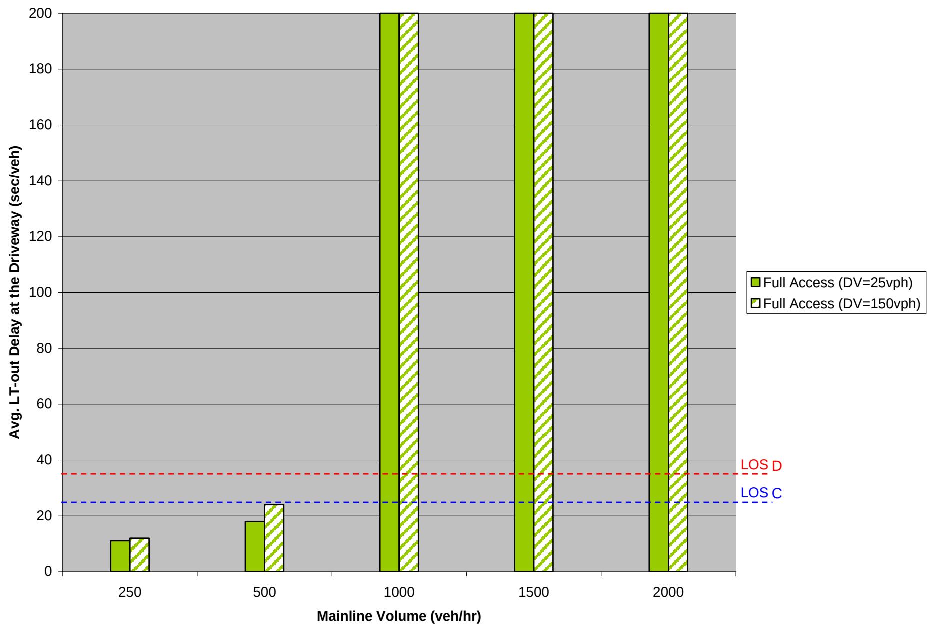


Figure 8-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

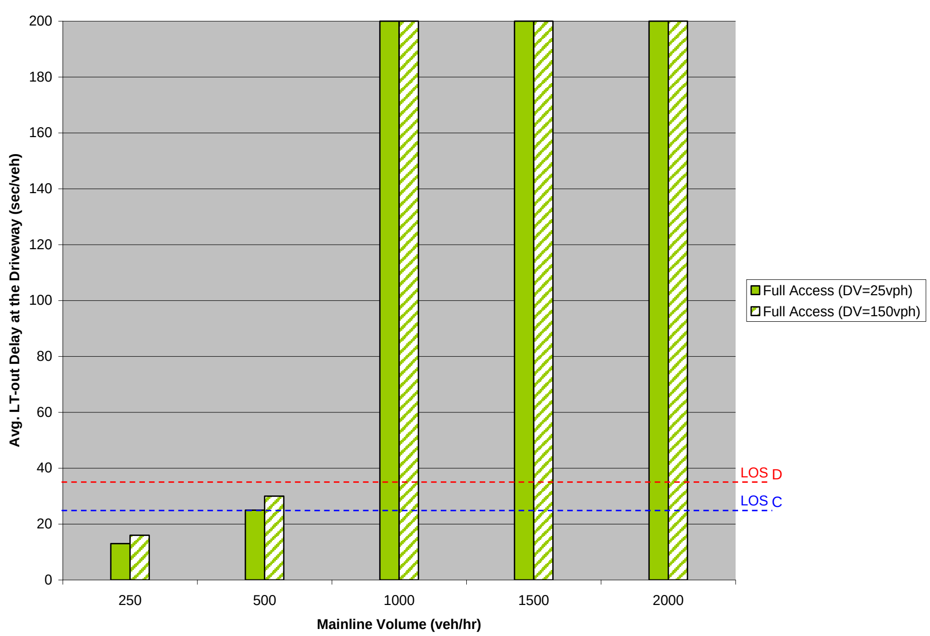


Figure 8-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=350ft)

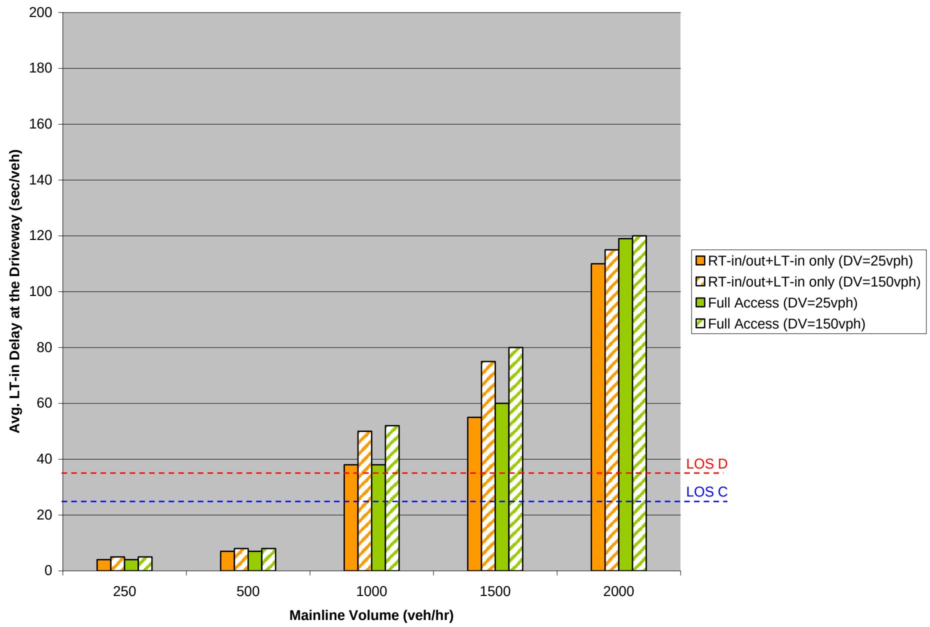


Figure 8-9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

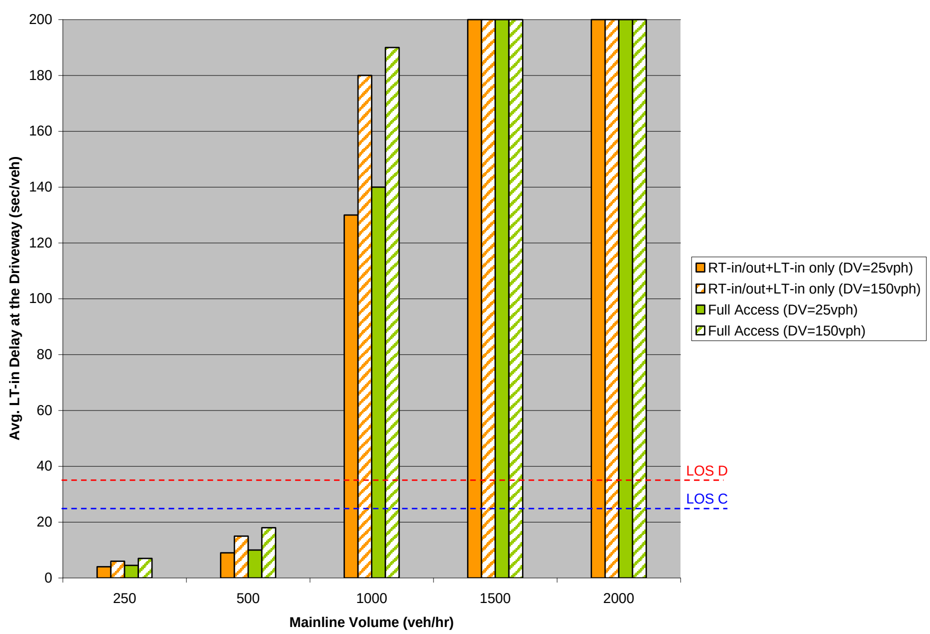


Figure 8-10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=350ft)

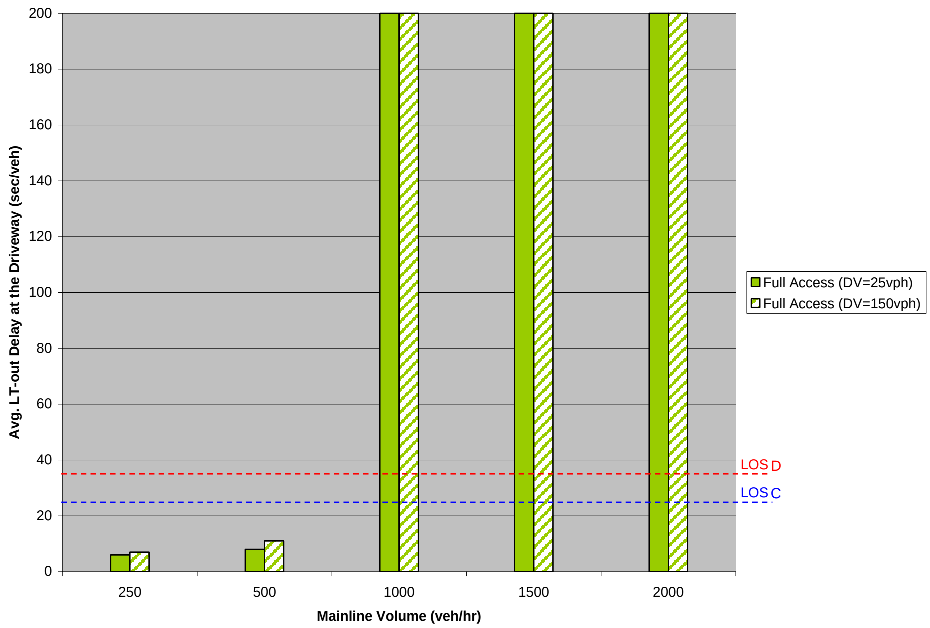


Figure 8-11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

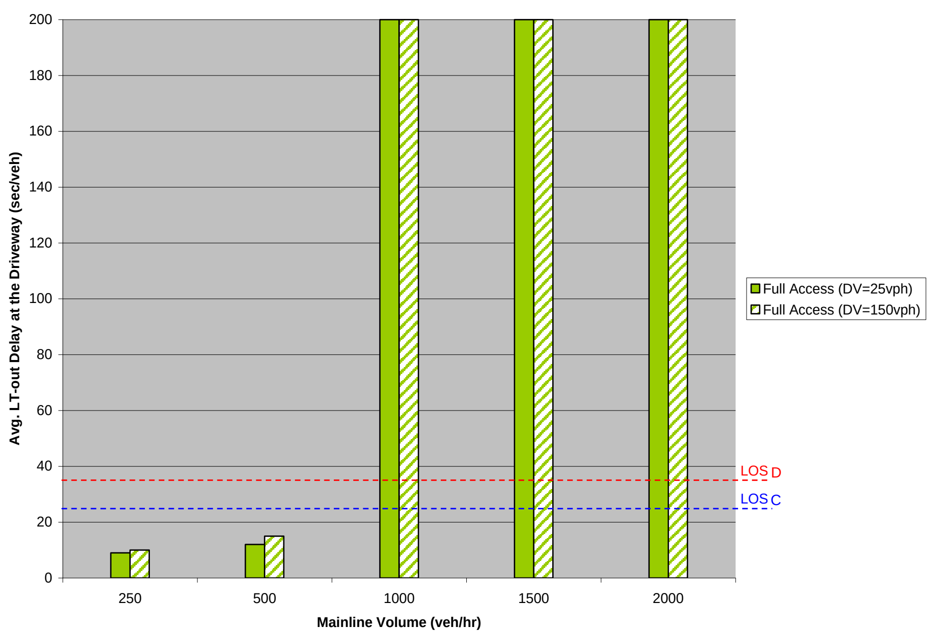


Figure 8-12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

50th Percentile Queue Length (ft)

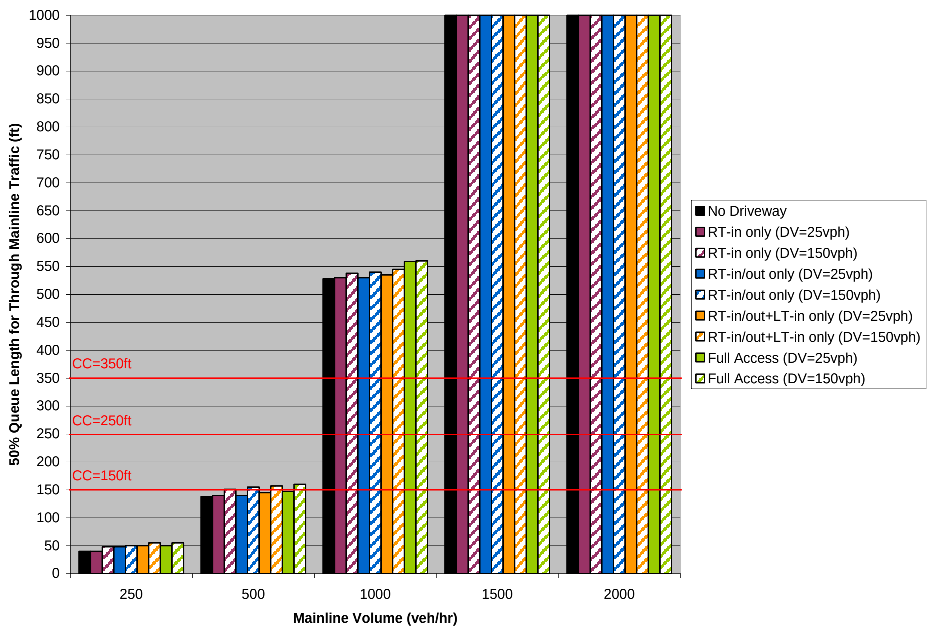


Figure 8-13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

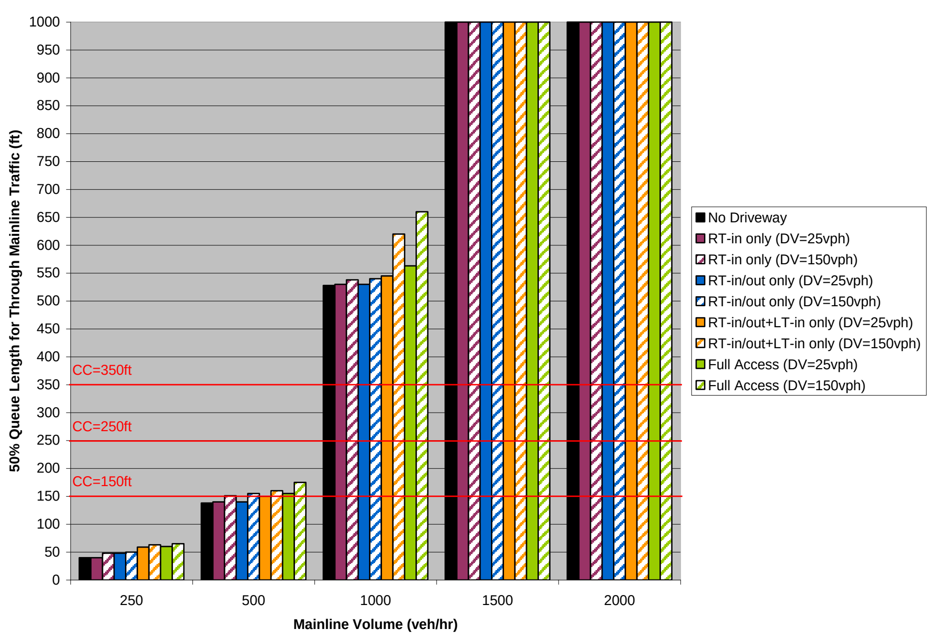


Figure 8-14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Appendix 9. Results for Model 5

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

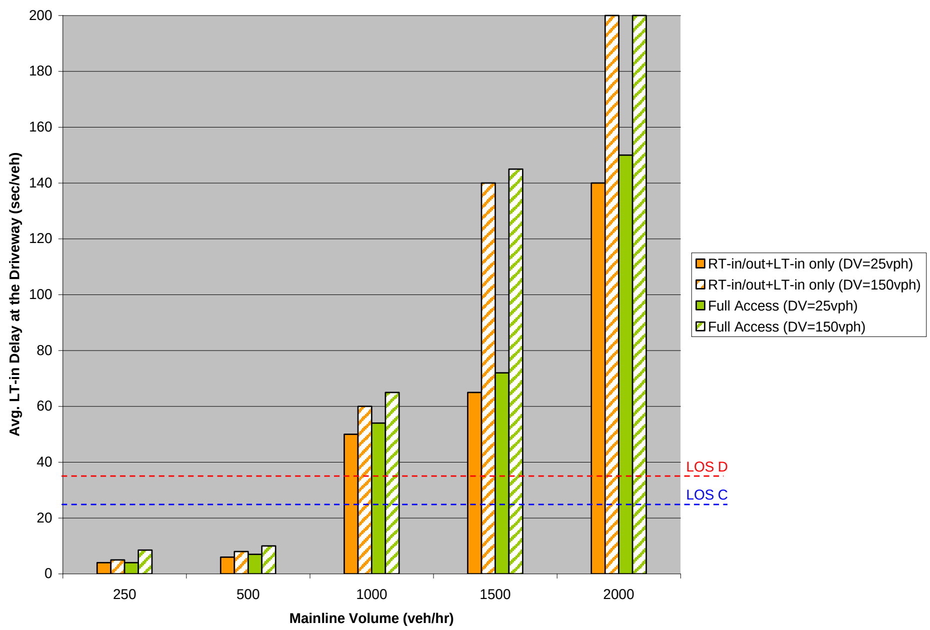


Figure 9-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

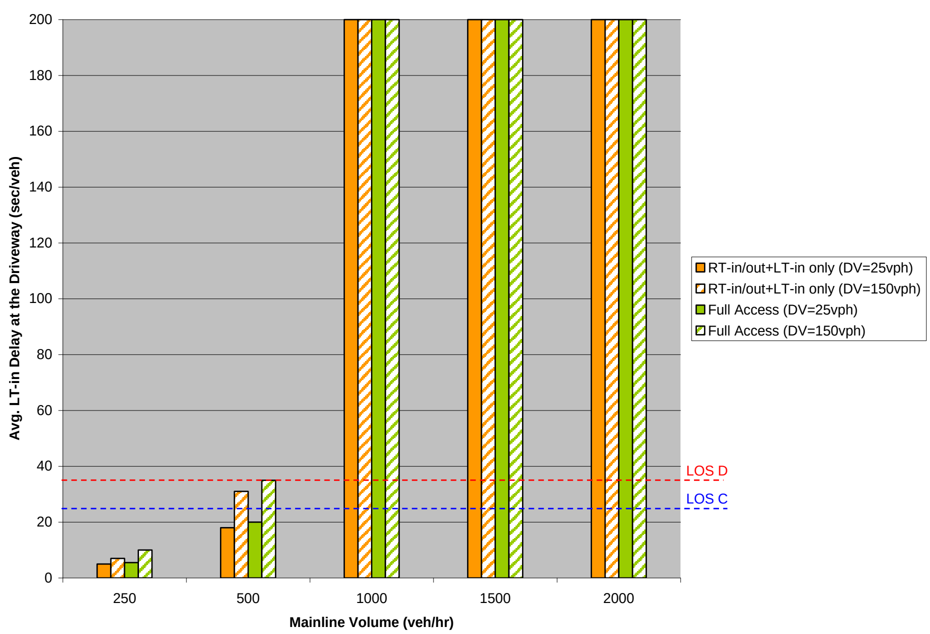


Figure 9-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

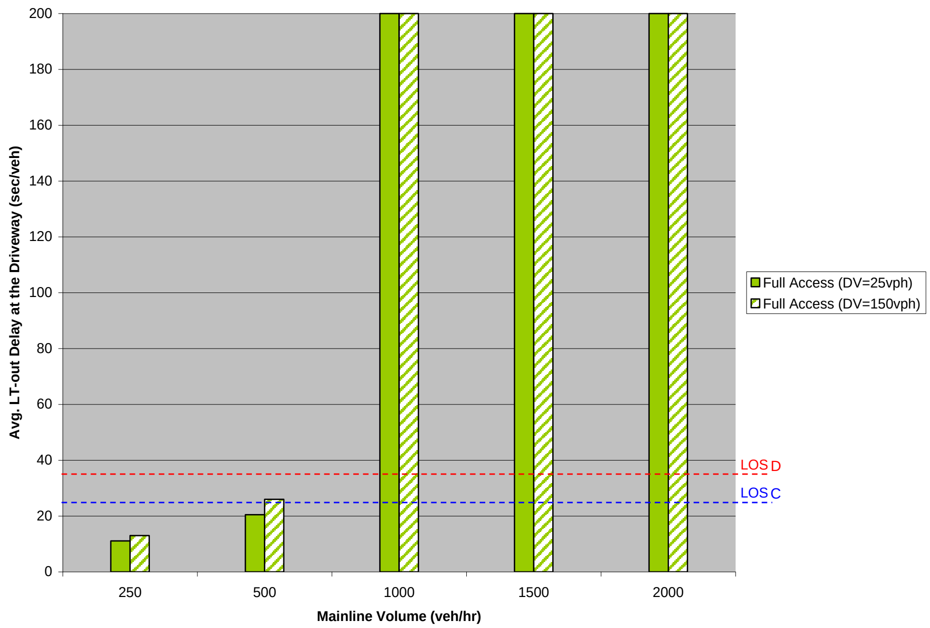


Figure 9-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

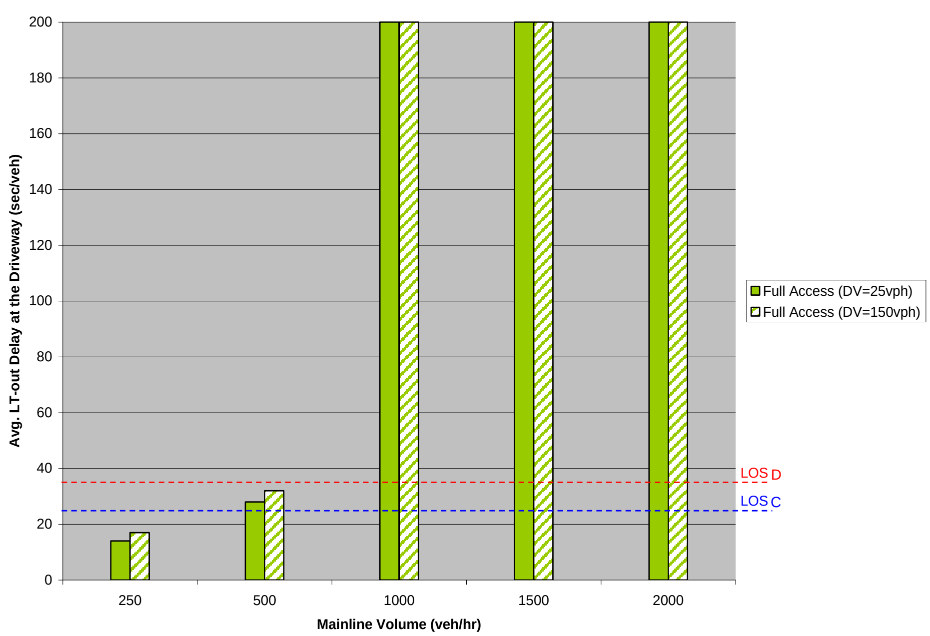


Figure 9-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=250ft)

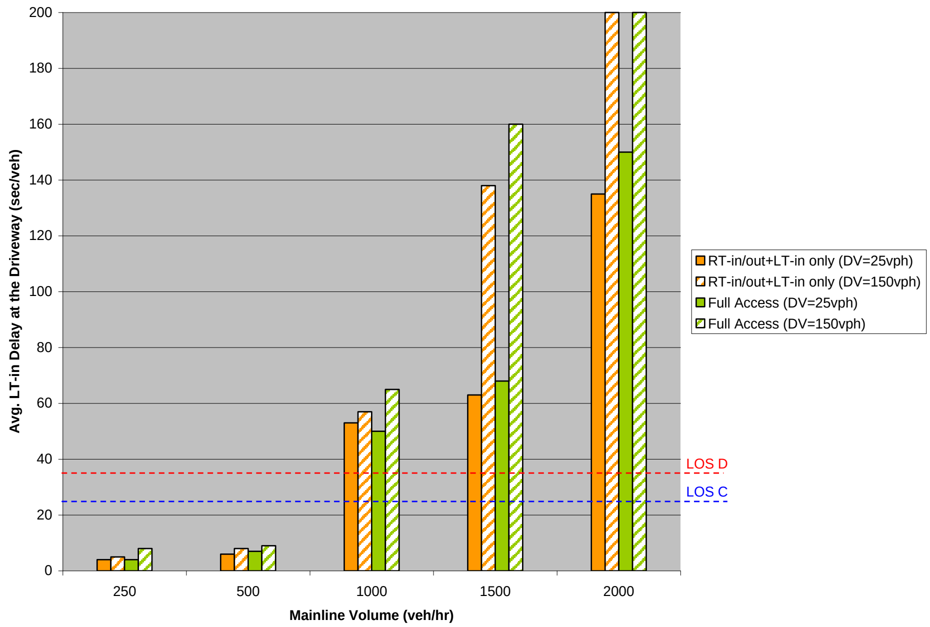


Figure 9-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

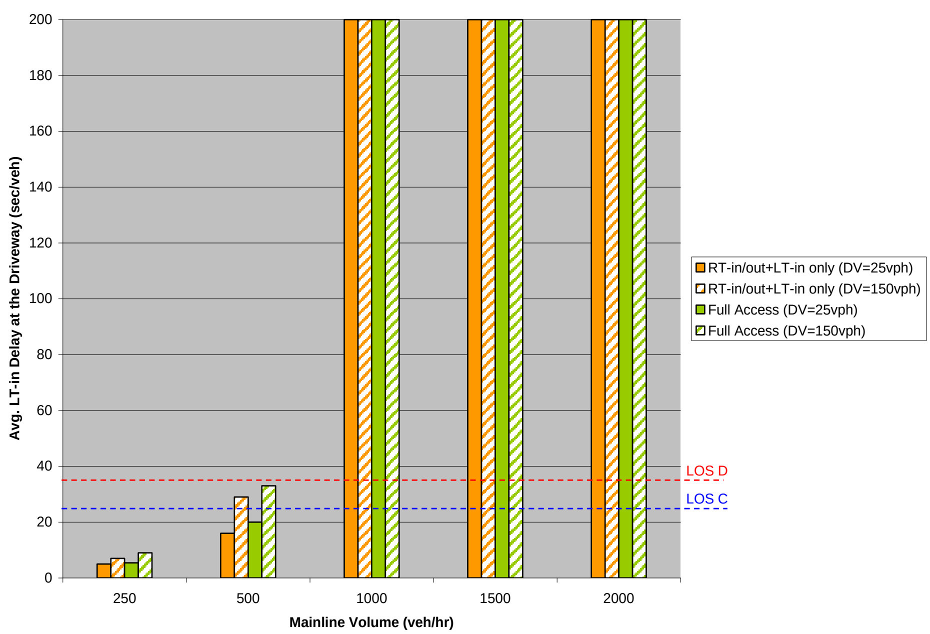


Figure 9-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

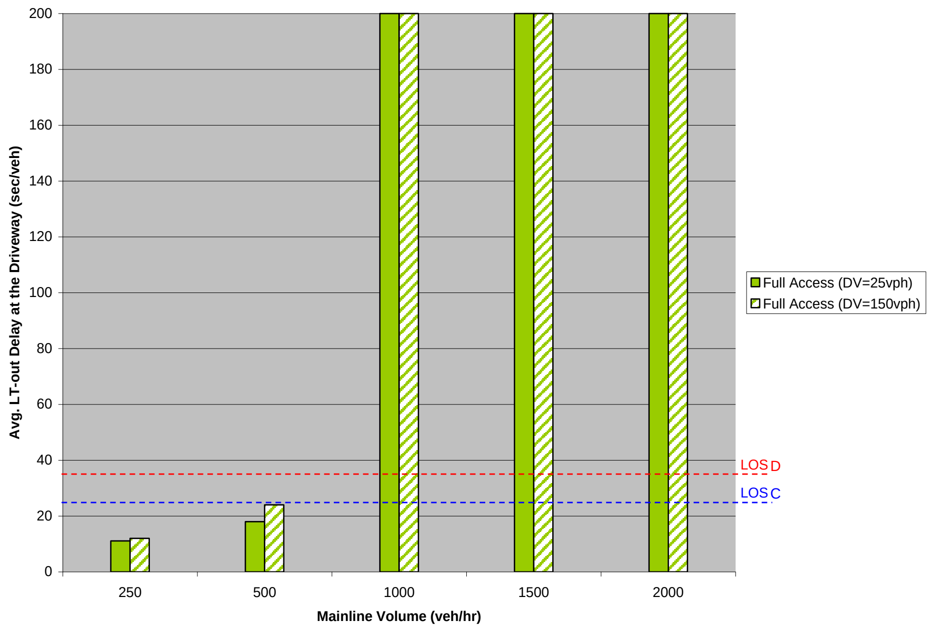


Figure 9-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

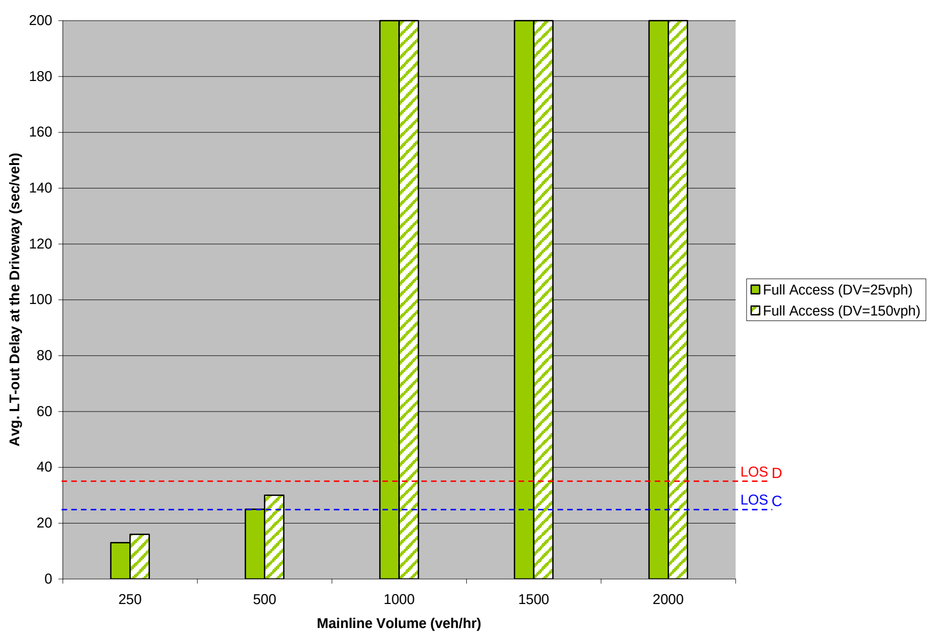


Figure 9-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for ***LT-in traffic*** for different turning volumes (CC=350ft)

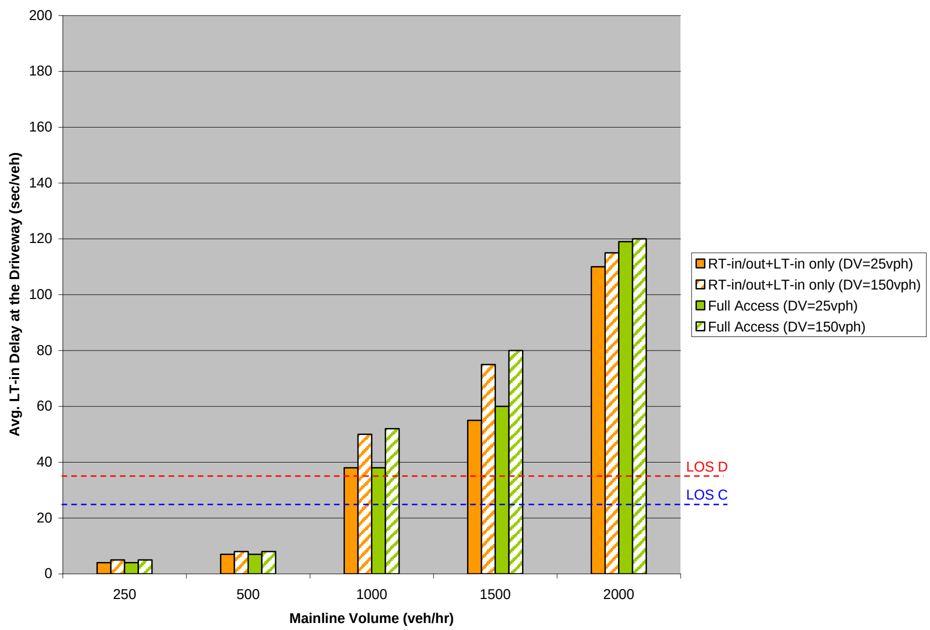


Figure 9-9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

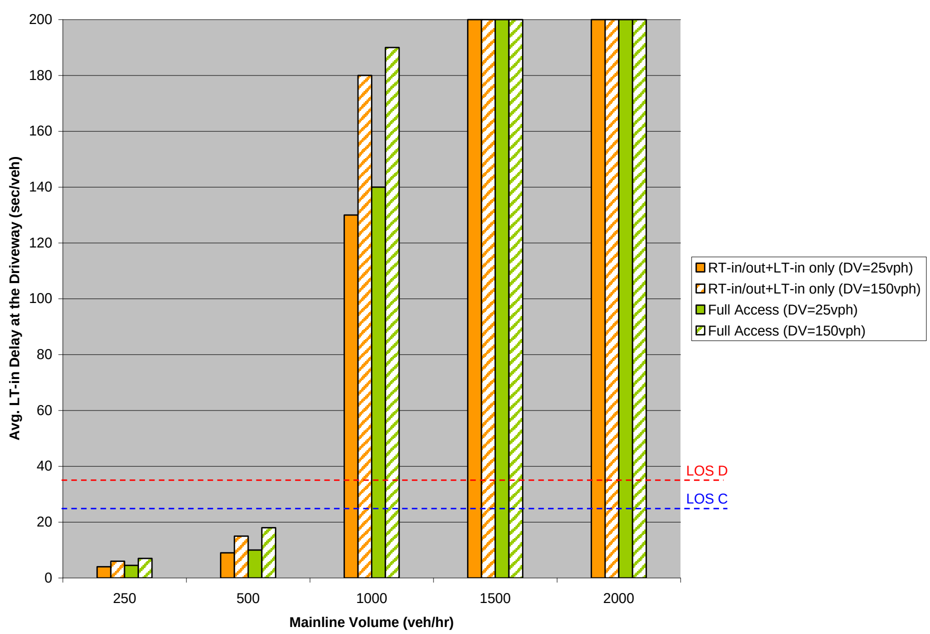


Figure 9-10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *<u>LT-out traffic</u>* for different turning volumes (CC=350ft)

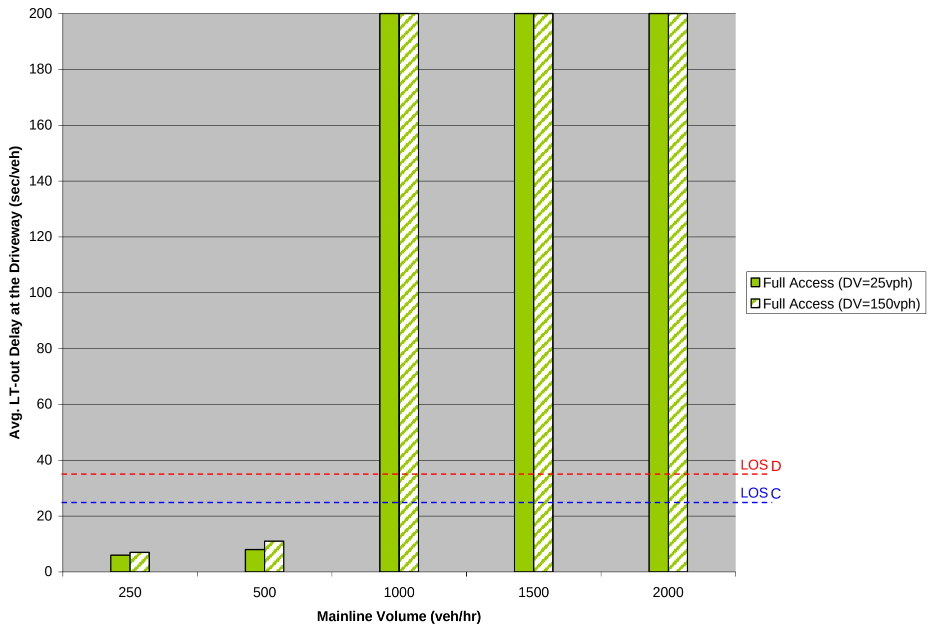


Figure 9-11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

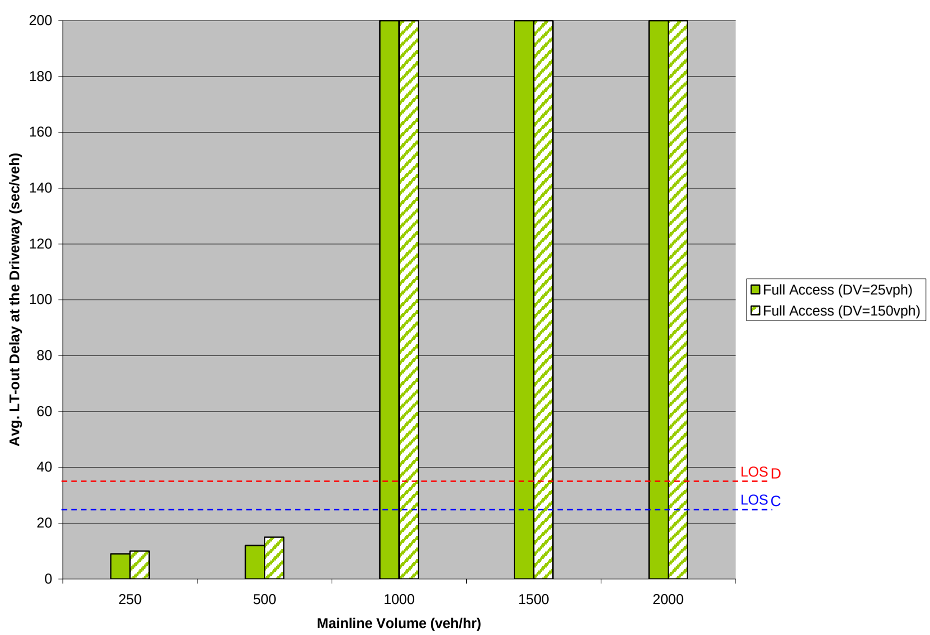


Figure 9-12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

50th Percentile Queue Length (ft)

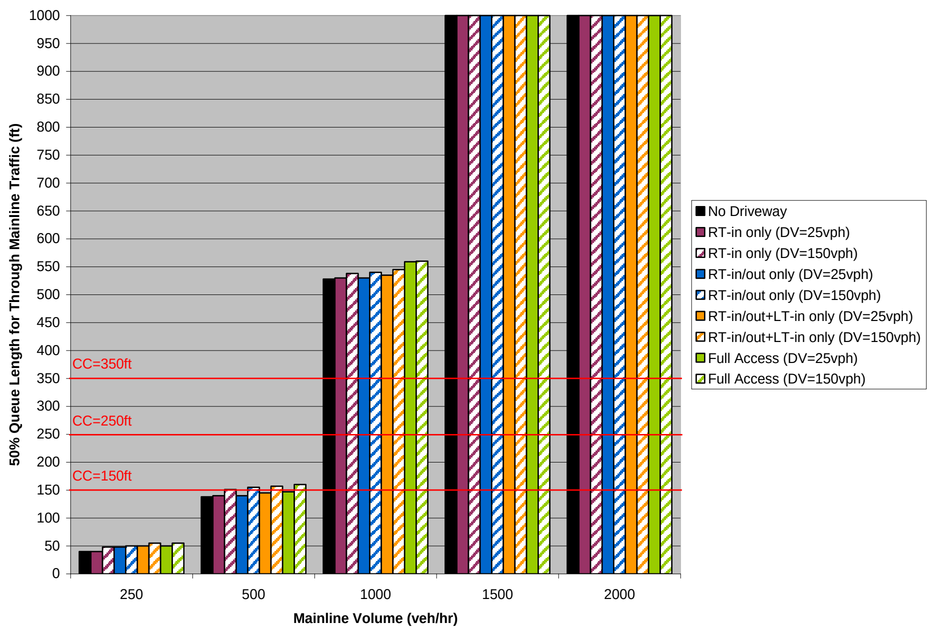


Figure 9-13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

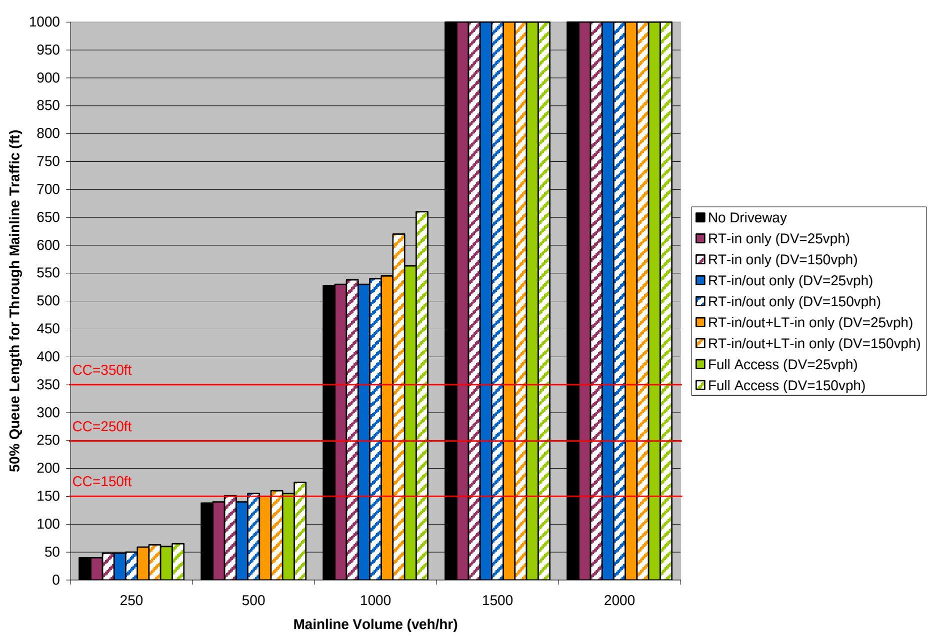


Figure 9-14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Appendix 10. Results for Model 6

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

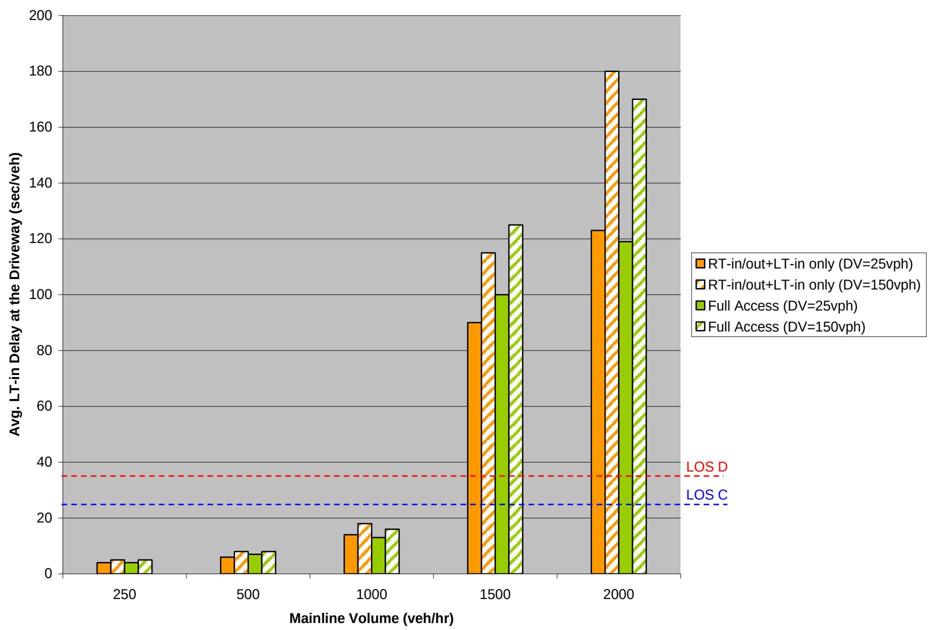


Figure 10-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

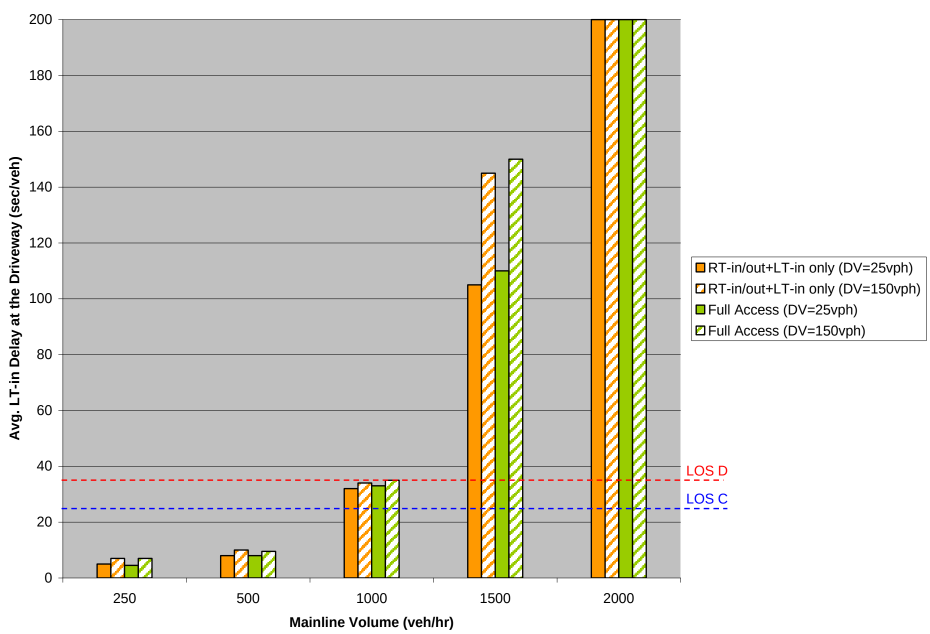


Figure 10-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

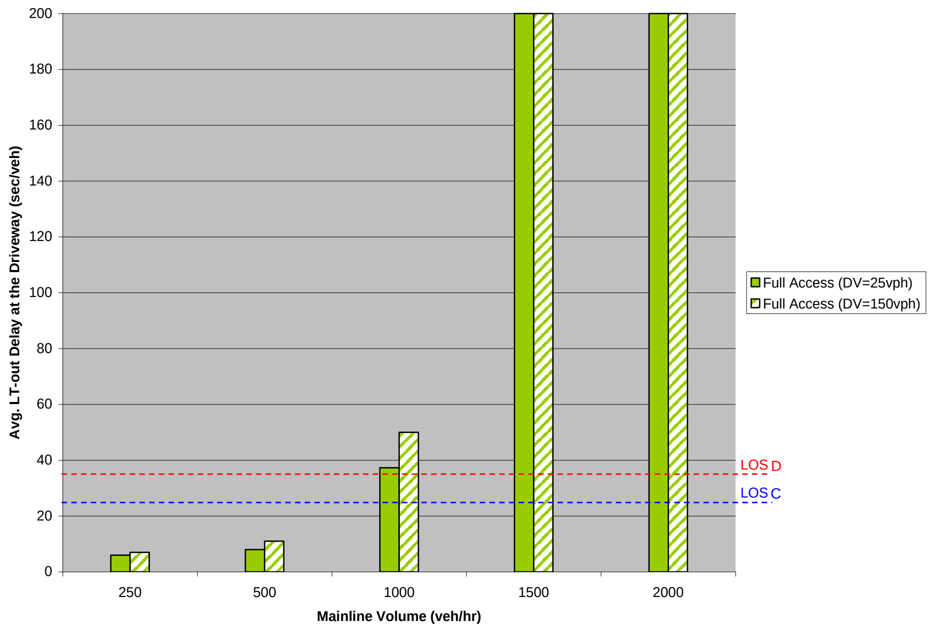


Figure 10-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=10vph***

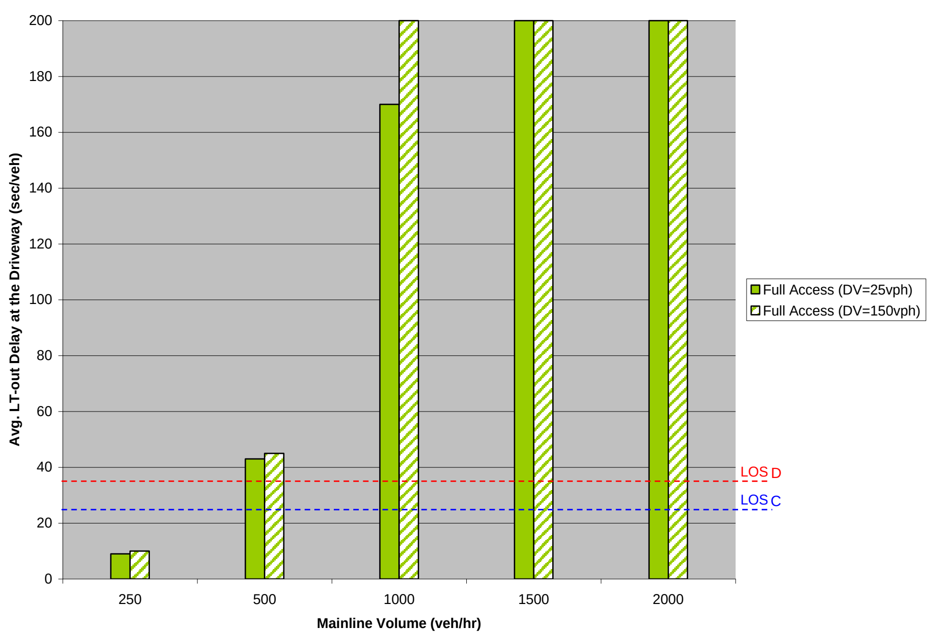


Figure 10-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=150ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=250ft)

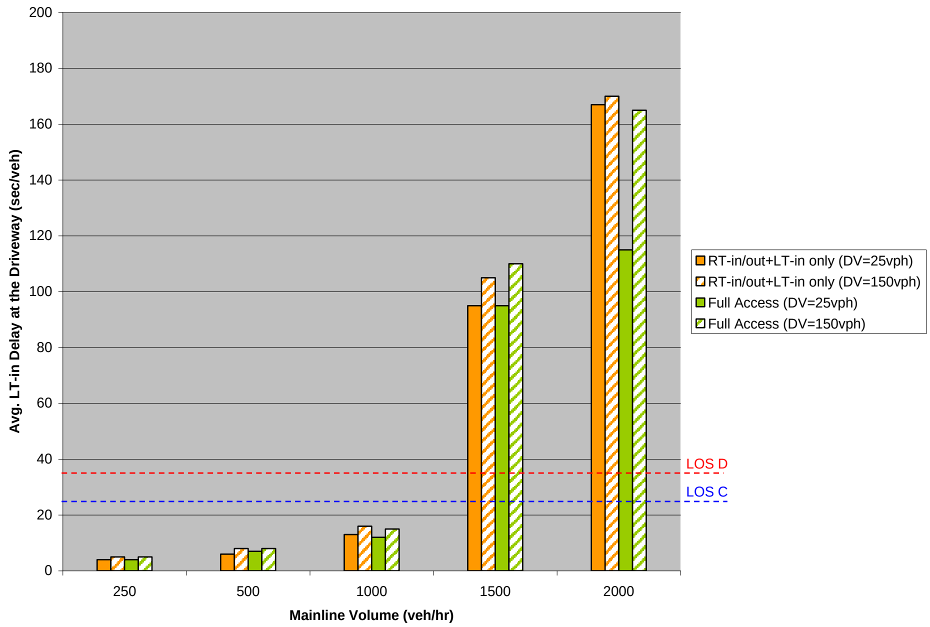


Figure 10-5. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

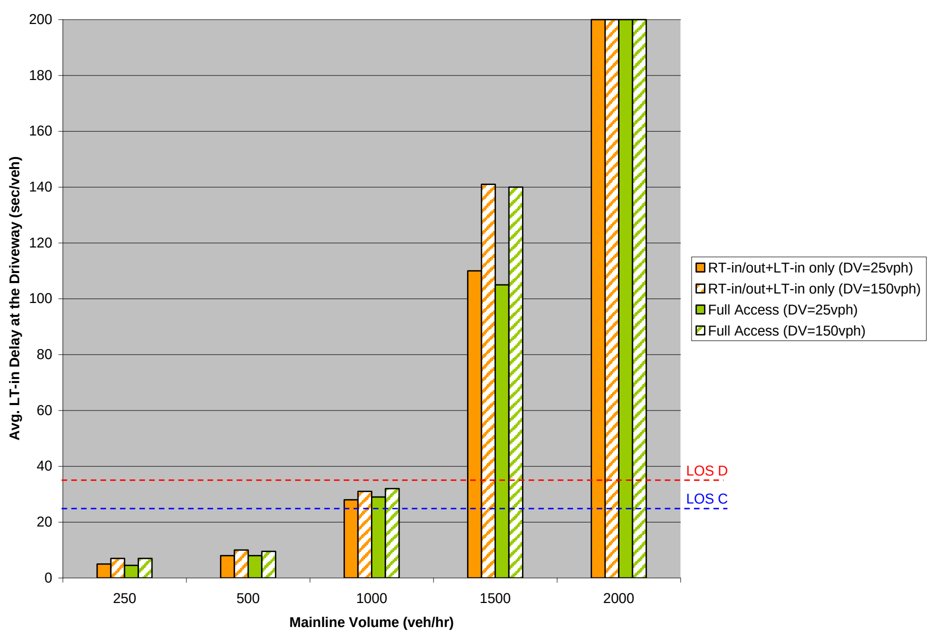


Figure 10-6. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=250ft)

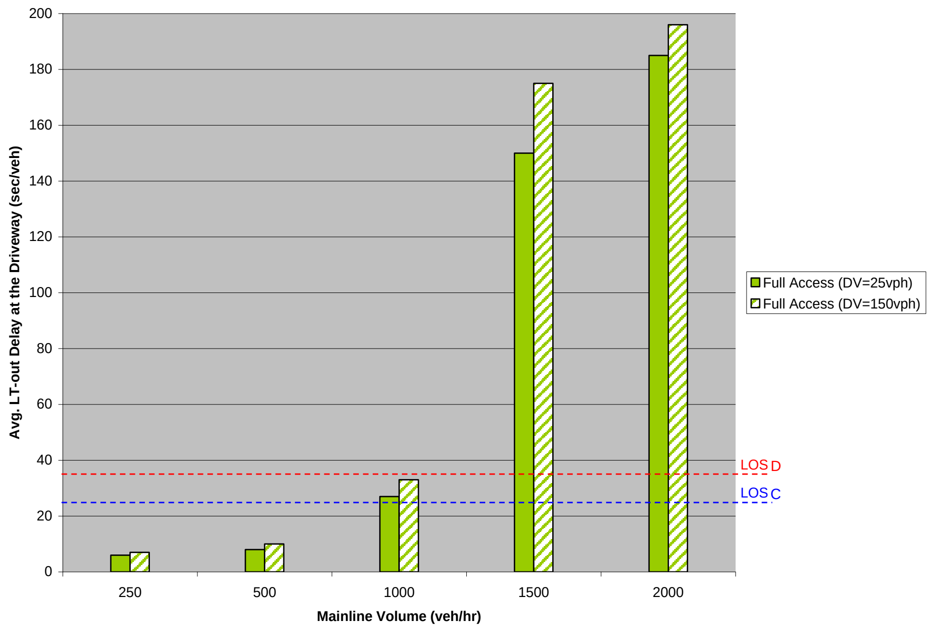


Figure 10-7. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=10vph***

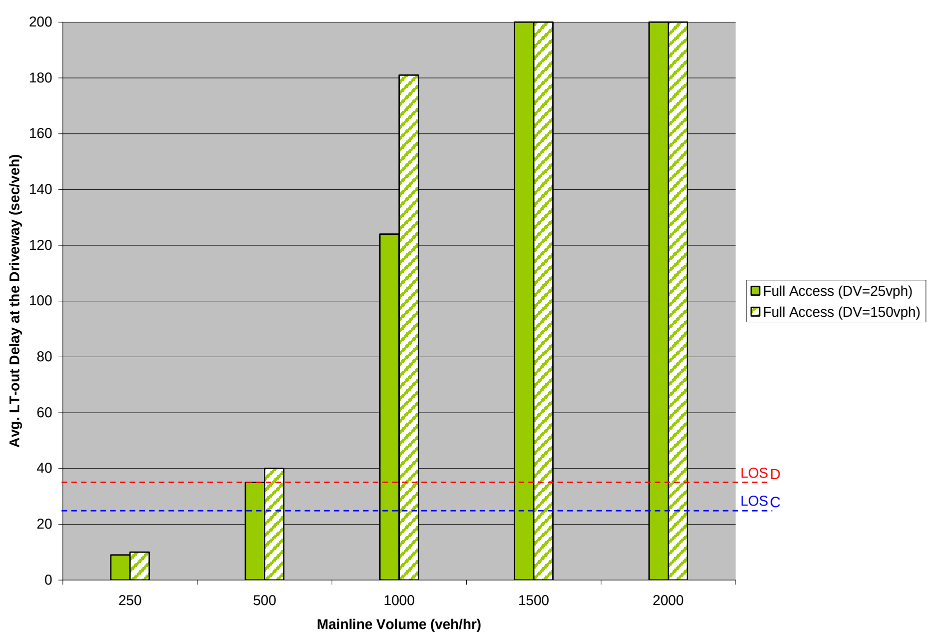


Figure 10-8. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for CC=250ft, and ***LT-in Vol=50vph***

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=350ft)

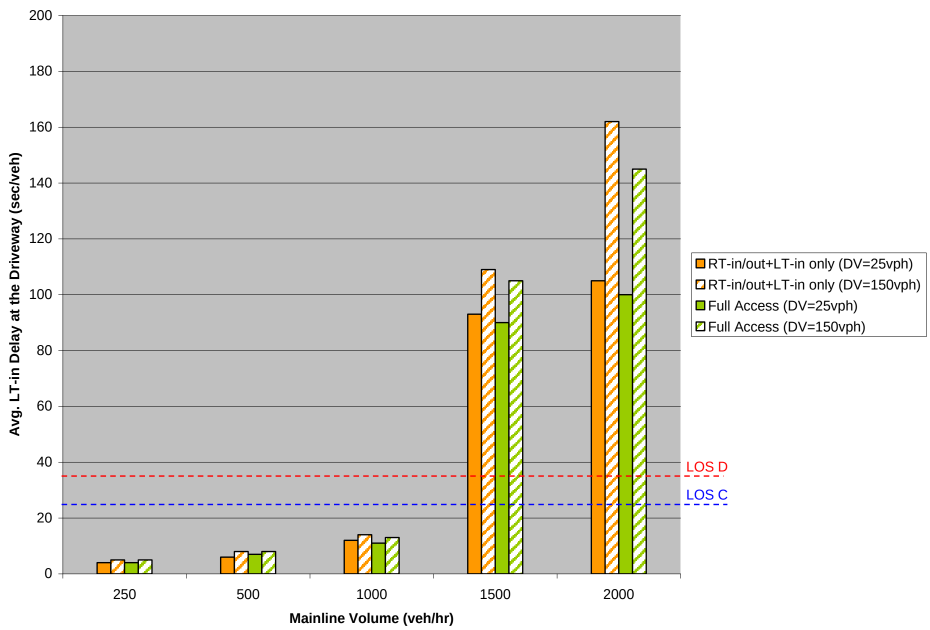


Figure 10-9. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=10vph***

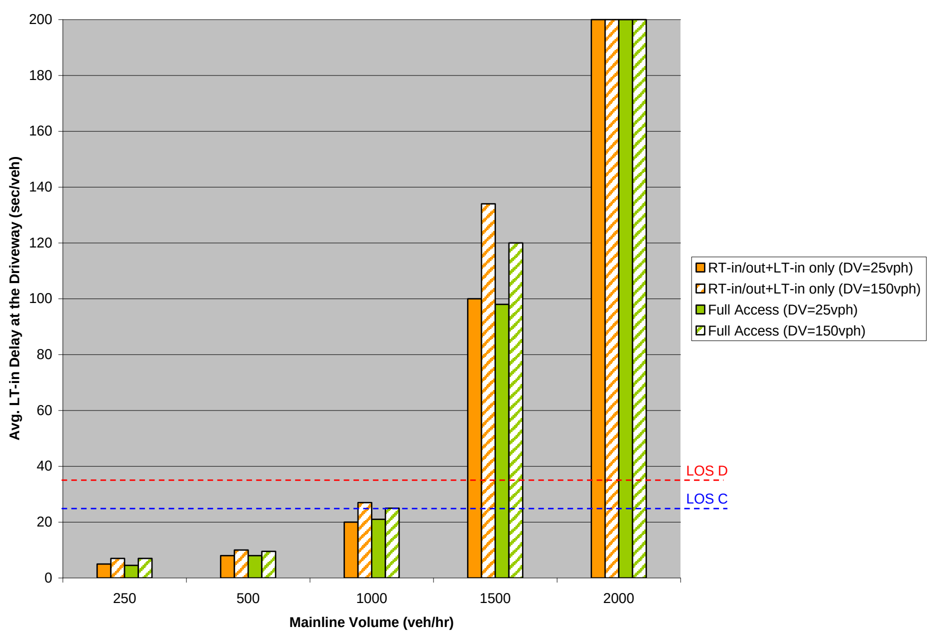


Figure 10-10. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for CC=350ft, and ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=350ft)

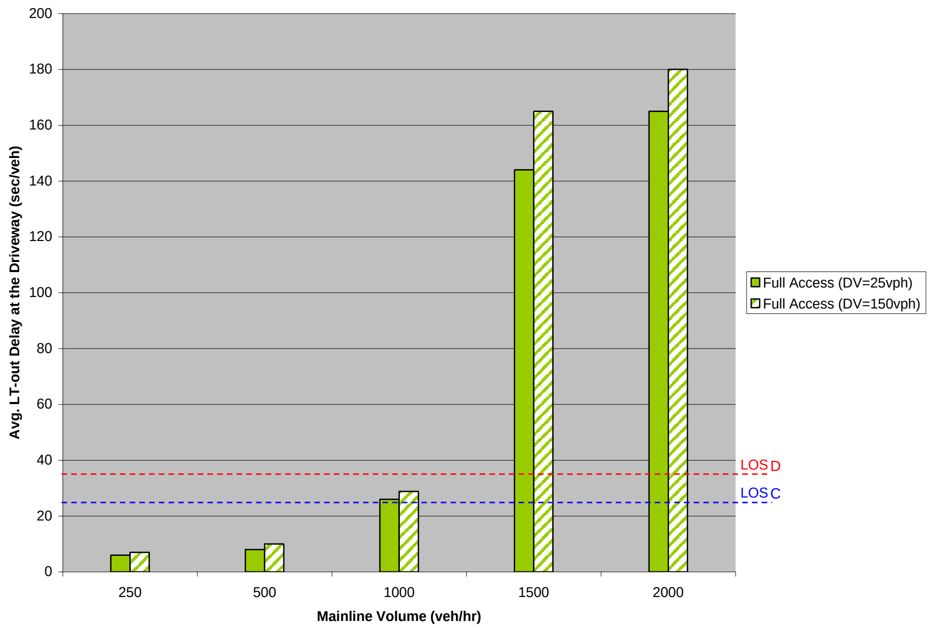


Figure 10-11. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph)

for CC=350ft, and ***LT-in Vol=10vph***

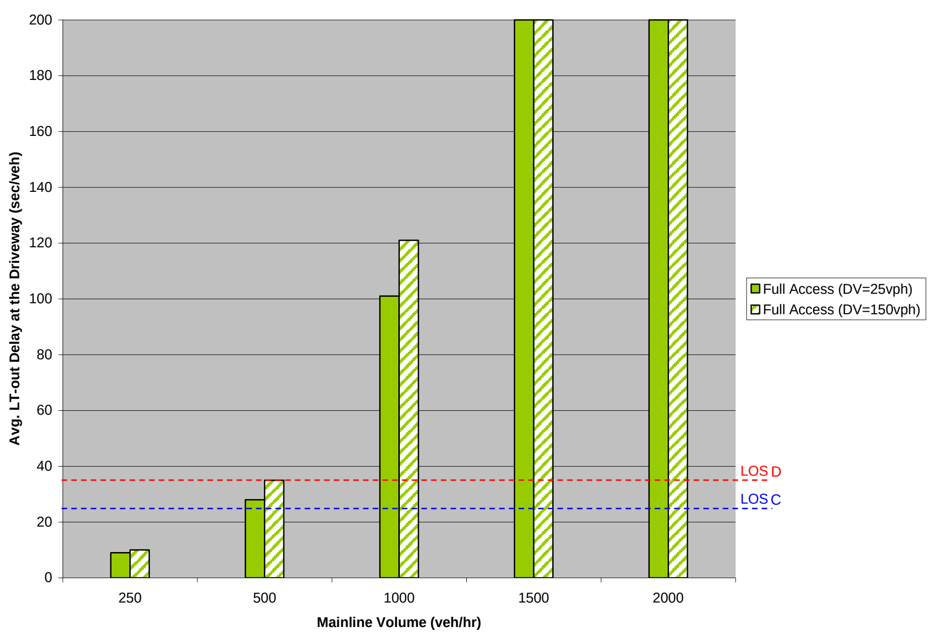


Figure 10-12. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph)

for CC=350ft, and ***LT-in Vol=50vph***

50^{th} Percentile Queue Length (ft)

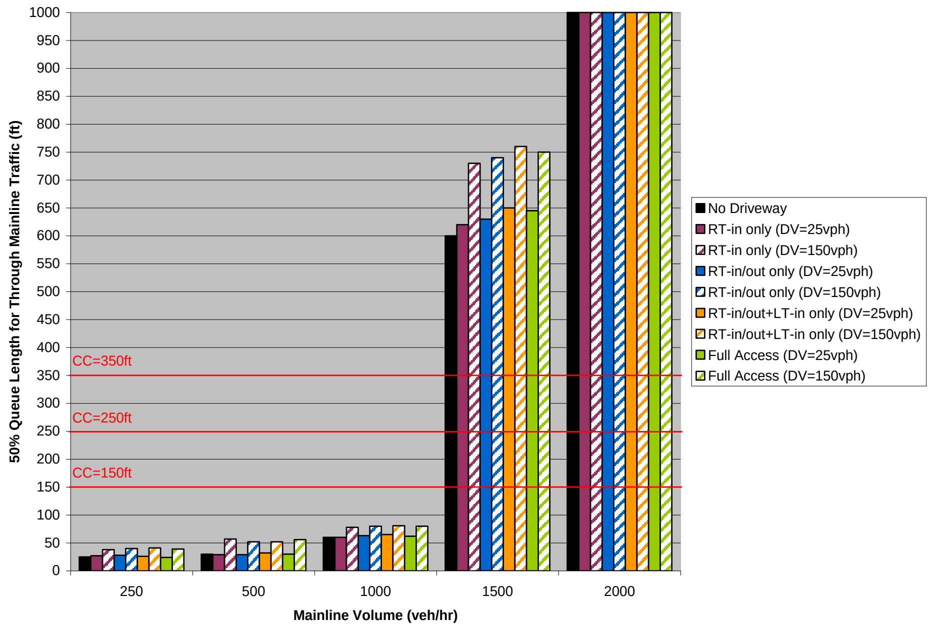


Figure 10-13. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=10vph**

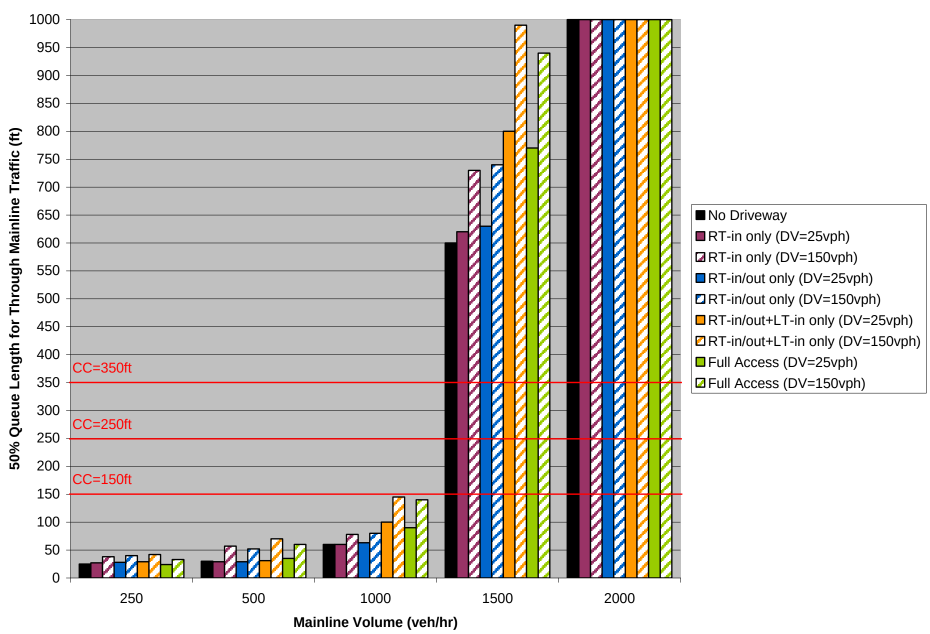


Figure 10-14. Comparison of 50% Queue Length (ft) for Through Traffic vs. Mainline Volume (vph) for **CC=150ft, 250ft and 350ft, LT=50vph**

Appendix 11. Results for Model 7

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

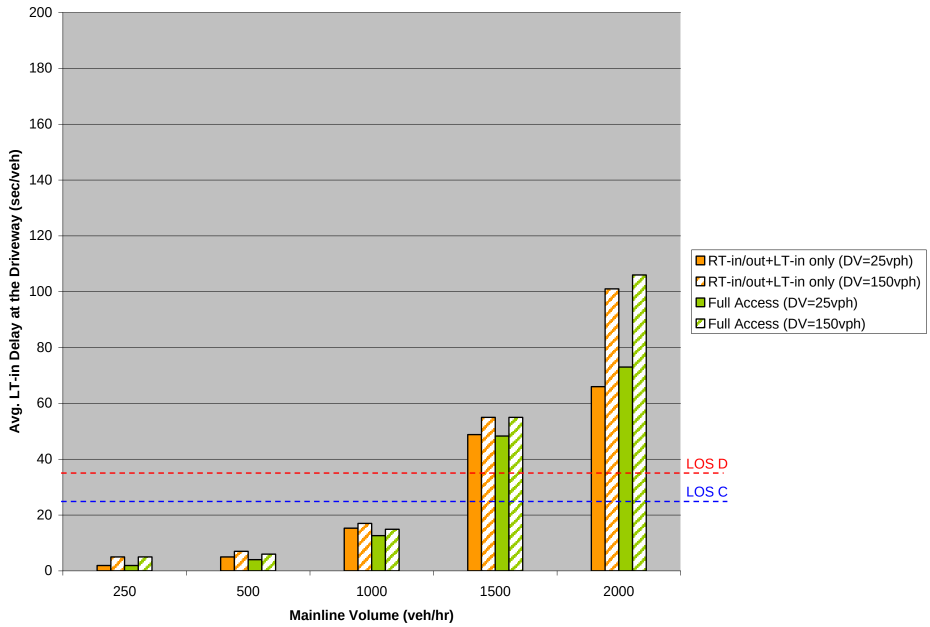


Figure 11-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=10vph***

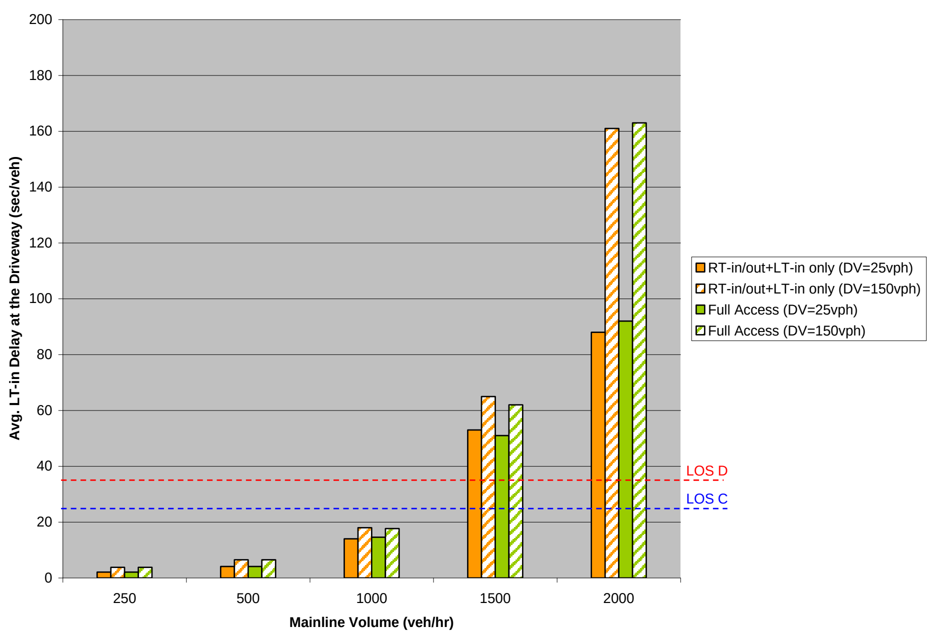


Figure 11-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

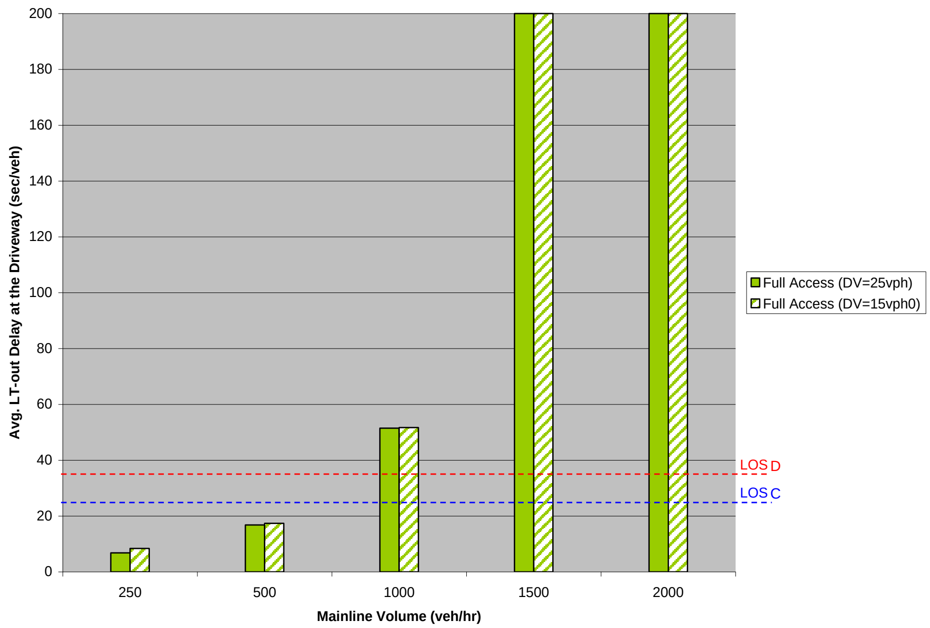


Figure 11-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=10vph***

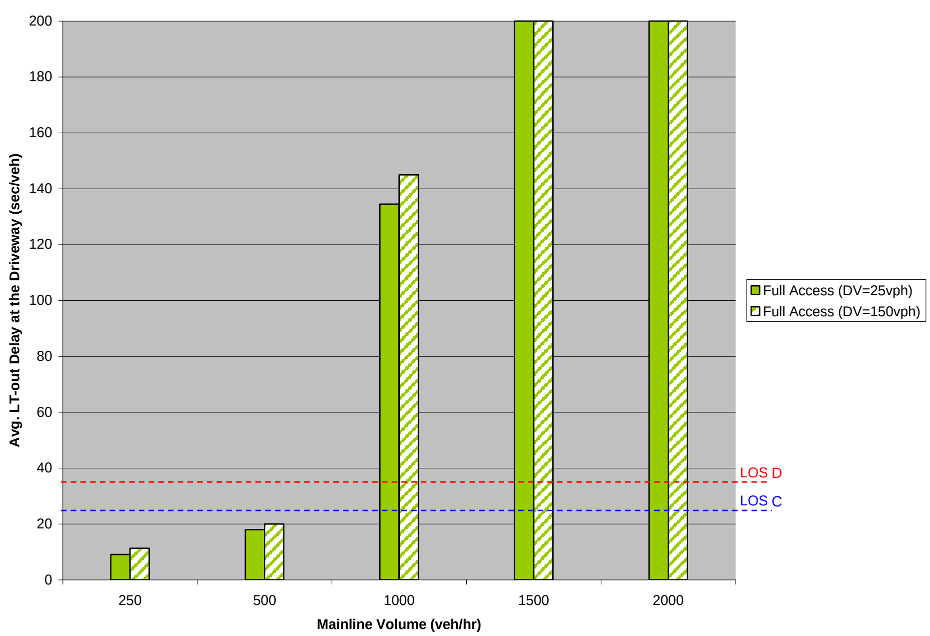


Figure 11-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=50vph***

Appendix 12. Results for Model 8

Average delay (sec/veh) for *LT-in traffic* for different turning volumes (CC=150ft)

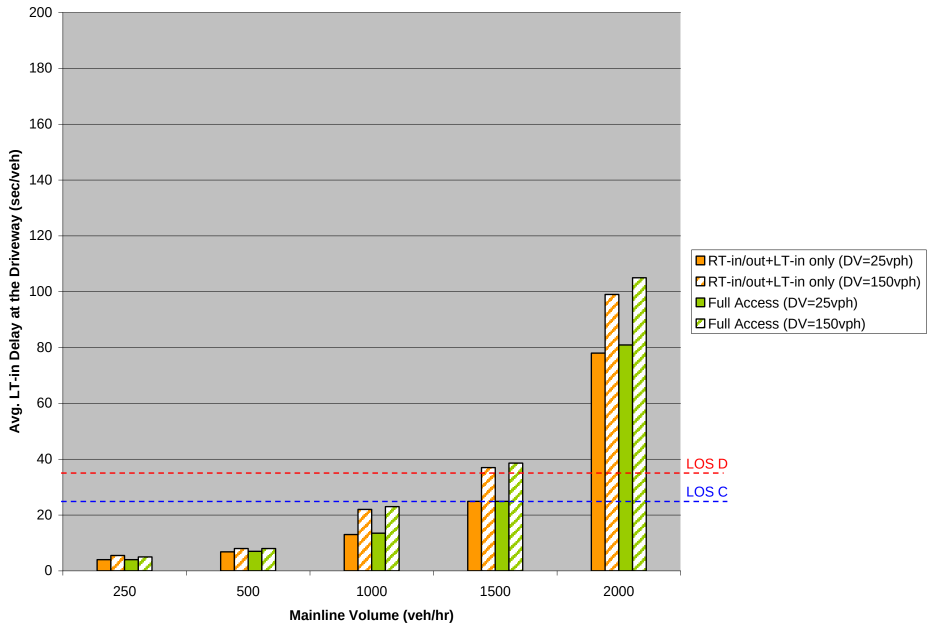


Figure 12-1. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=10vph***

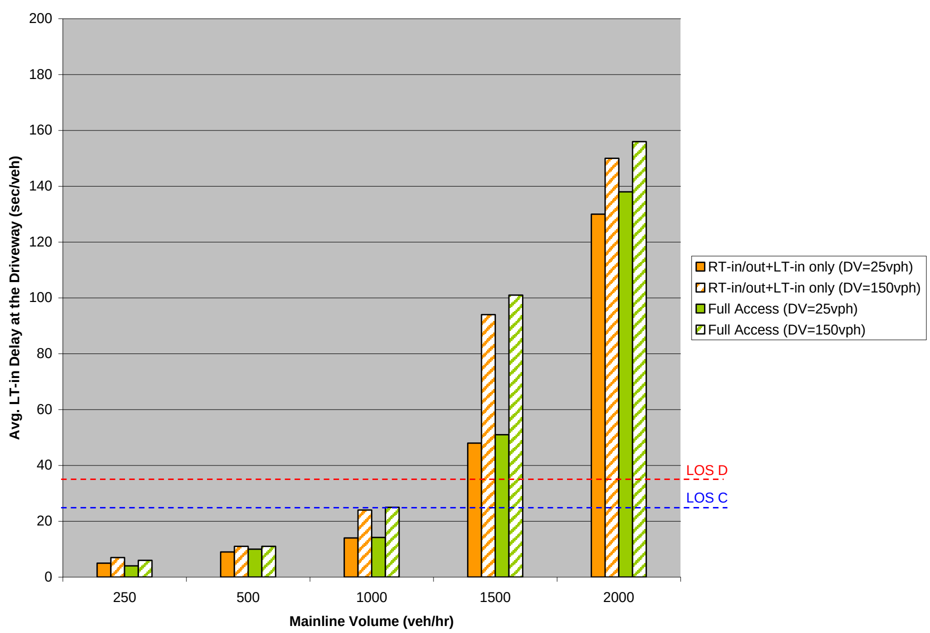


Figure 12-2. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=50vph***

Average Delay (sec/veh) for *LT-out traffic* for different turning volumes (CC=150ft)

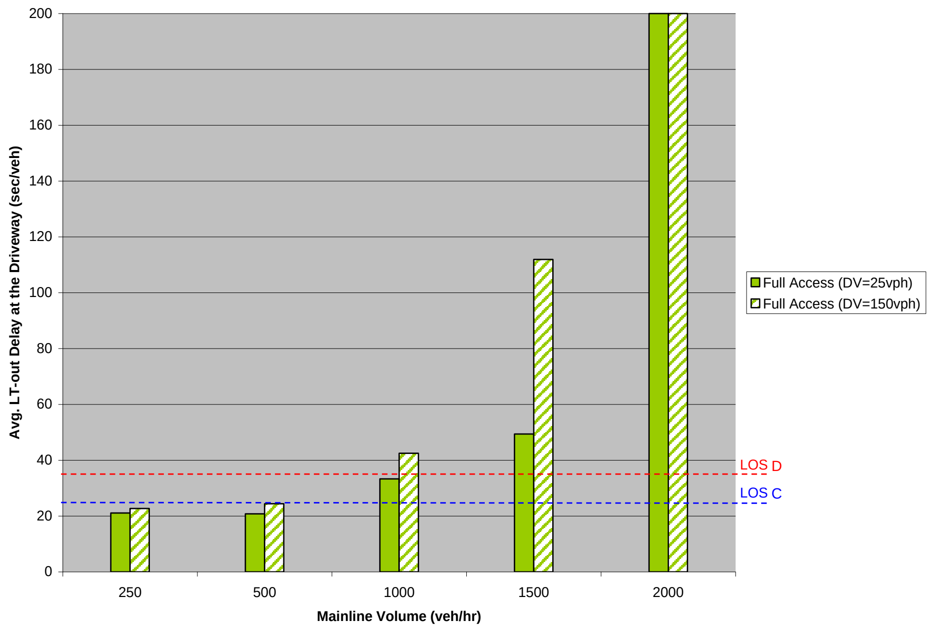


Figure 12-3. Comparison of Average LT-out Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=10vph***

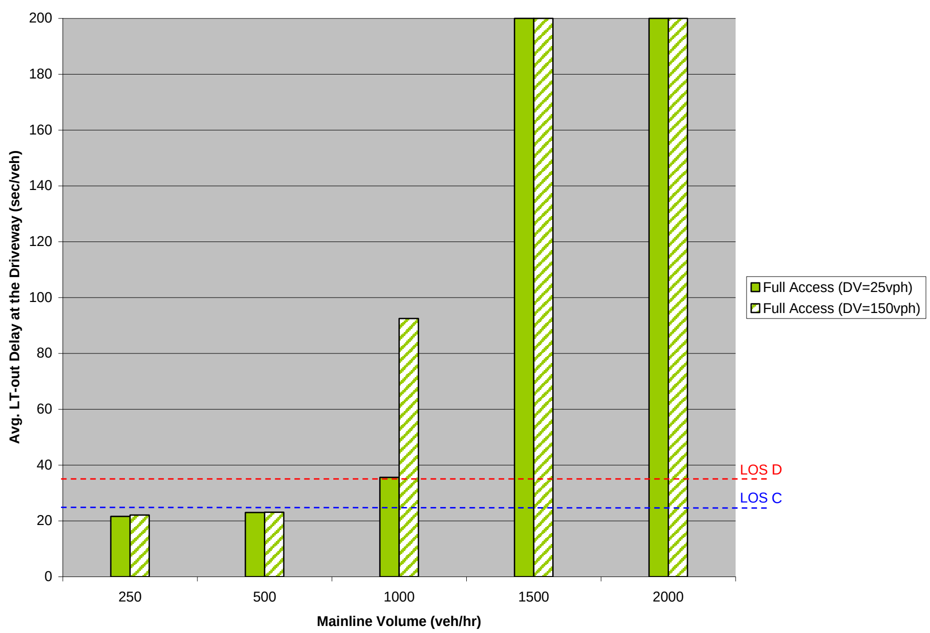


Figure 12-4. Comparison of Average LT-in Delay (sec/veh) vs. Mainline Volume (vph) for ***LT-in Vol=50vph***