

Evaluating the Effects of Prohibiting Left Turns and the Resulting U-Turn Movement

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16. Abstract The objective of this research was to evaluate the operational and safety effects of restricting direct left turns from a driveway and providing alternatives to accommodate the left turn deterred traffic. This study was conducted in three phases: survey of state agencies, operational analysis, and safety assessment. Very little operational difference was found between no restrictions on direct left turns versus the restrictions with the U-turn alternative movements from site to site. While changes in the traffic volumes on the mainline had an impact in specific instances, no definite trends were apparent. As a result of all findings in this study, it is proposed that alternatives must be evaluated on a site-by-site basis. This study also found the jughandle design 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. The safety assessment revealed that a right turn followed by a U-turn movement is safer than the direct left turn.		13. Type of Report and Period Covered Final Report	
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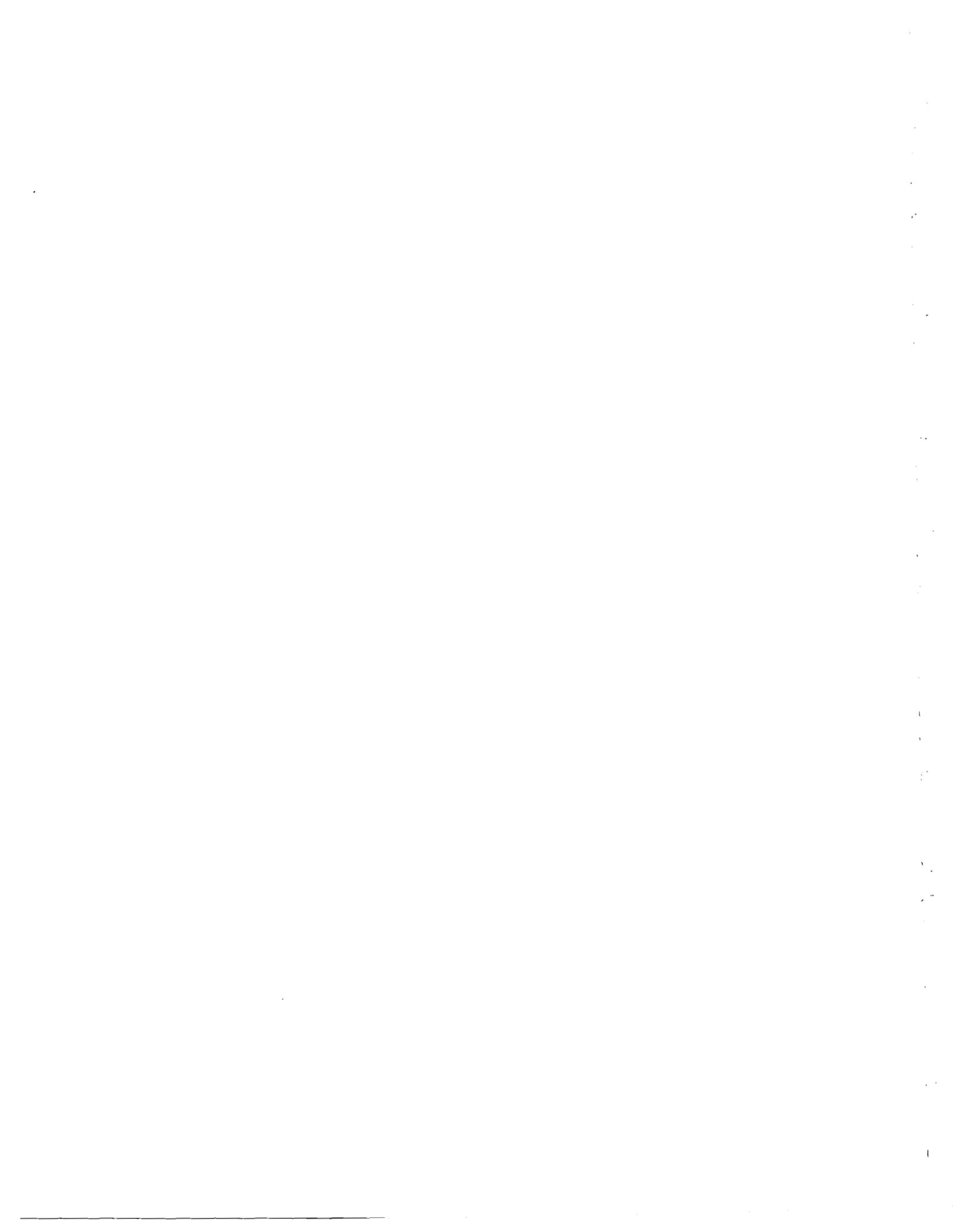
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1. INTRODUCTION

1.1 Problem Statement

The Ohio Department of Transportation's (ODOT) State Highway Access Management Manual establishes procedures and standards for providing a balance between accessibility to business, residential, and commercial development and traffic mobility along the roadways surrounding a development (ODOT 2001). The Manual defines operational standards, functions, and specifications for a comprehensive set of access-related items, including the location and spacing of access connections and their safety, design, and construction standards; the location and spacing of traffic control devices; and requirements for intersection treatments.

The ODOT State Highway Access Management Manual does not address the effects of prohibiting left turns from a roadside facility through the use of right-in/right-out restrictions on traffic movement. Left turn treatments at driveways and street intersections are an important element of access management.

The combination of a right turn and U-turn as opposed to a direct left turn is expected, in many instances, to significantly reduce traffic conflict points and improve safety, depending on traffic and geometric conditions. Based on the jurisdiction and traffic, it may be necessary to provide protected-only phases for U-turns. However, there is a lack of field data to prove these theories. Also, motorists often do not favor the forced right turn then U-turn due to the perception of a longer travel time compared to the direct left turn.

1.2 Objectives

The objective of this research is to evaluate the operational and safety effects of restricting direct left turns from a driveway and providing alternatives to accommodate the left turn deterred traffic.

1.3 Literature Review

The literature summarized by the research team was separated into two categories. The first category included studies that focused on the effects of restricted left turns, and the second included studies that proposed and/or evaluated alternative movements for the left-turn deterred traffic.

Because only a few studies have been undertaken to conclusively and comprehensively assess the effects of providing U-turns to replace direct left turns from a development, the operational and safety effects of providing U-turns as an alternative to direct left turns are still not clearly established. Most states have not enacted standards to provide U-turns as an alternative to direct left turns because of the lack of available data by which to conclusively set standards.

Two papers by Joseph Hummer identified several left-turn alternatives at intersections that can be used to relieve congested arterials. These included median U-turn, bowtie, superstreet, paired



intersections, jughandle and continuous flow intersection (Hummer, September 1998 and Hummer, November 1998). The practicality of these alternatives for accommodating left turn deterred traffic from the driveway would depend on several factors, including right-of-way requirements, construction, maintenance, and operations costs, driver and pedestrian friendliness, operational impacts in the corridor, and impacts on potential conflicts and crashes. For example, the Michigan-U turn alternative requires a 60-ft median, which may not be available in most cases using a left-turn restriction. Another example is a paired intersection, where additional right-of-way is required for parallel collector roads.

In recent years, the Florida Department of Transportation has been involved in several studies related to the safety and operational effects of restricting left turns. Florida prohibits any left turn exits onto major arterials through the use of median treatments. Mid-block U-turn lanes are provided to accommodate the diverted left-turn volume.

A Florida study found that by changing a direct left-turn from a driveway into a right-turn followed by a U-turn reduced the crash rate at driveway/roadway intersections by 22 percent at selected sites (Gluck 1999). Comparable or shorter travel times were found in earlier studies for right-turns followed by U-turns over direct left-turns from driveways under heavy traffic volume conditions. Data related to specific traffic and geometric conditions were not available for this study, therefore making it difficult to validate the results for Ohio.

Another such study sponsored by the FDOT evaluated the safety and operational effects of replacing direct left turns from a driveway with a right turn plus a U-turn movement at varying distances from a driveway (Zhou 2000). A study of two sites was performed to evaluate the right turn plus U-turn movement. These two sites were located on arterials with speed limits of 45 mph and 50 mph, respectively, with traffic volumes of 4600 vehicles per hour on the arterials. The following traffic data was collected from the two sites to compare the direct left turn to the right turn plus U-turn movement:

- average travel time
- waiting delay
- traffic conflict rate
- speed reduction

Following a preliminary analysis of the traffic data, the researchers concluded that the average waiting delay of the right turn plus U-turn traffic was less than the average waiting delay of the direct left-turning traffic. Also, the conflict rate for right turn plus U-turn was much less than that of the direct left-turn.

In this study, the total travel time of direct left turns was found to be less than the right turn plus U-turn movements when the direct left turn volume was low (less than 50 vehicles per hour). The main advantages found for the right turn plus U-turn movement of reduced travel time and delay was under moderate and high-volume conditions. However, some disadvantages were also observed in this study, such as increased waiting delay in low volume conditions and that the longer travel distance may consume more fuel in a right turn followed by a U-turn than in the case of a direct left turn.



Although the Florida Department of Transportation study may shed some light on the effects of restricting direct left turns for various volume conditions, any consideration of the applicability of the study results to other states must take into account the geometric and traffic conditions at the study sites. Traffic conditions in the Florida study such as speed and vehicle mix may vary from the conditions of the sites in this study, rendering them totally invalid for differing geometric and traffic scenarios in other states. In addition, the Florida study did not consider weaving problems that could exist when a vehicle turns right from a business and crosses over several lanes of traffic to the left-turn lane. This problem should be carefully evaluated for roadways.

The Michigan Department of Transportation (MDOT) has prohibited direct left turns at signalized intersections for more than forty years (Levinson 2001). In order to accommodate the left-turn movement, a directional U-turn crossover downstream from the intersection improves safety and capacity along wide median-divided highways. This configuration permits two-phase traffic signal control, which increases capacity and improves safety at intersections. MDOT has installed median U-turns along divided highways where the central medians are at least 50 to 60 feet wide. The 60-foot median is required to accommodate WB-50 trucks on a six-lane highway; the width can drop to 50 feet for an eight-lane highway. However, if encroachment into an auxiliary right-turn lane is allowed, the median width may be reduced by ten feet. Another design consideration for the median U-turn is the location of the crossover. MDOT recommends placement 660 ± 100 feet from the signalized intersection.

The benefits of such a configuration have been recognized through the years. The indirect left-turn has led to lower crash rates, increased capacity, decreased total travel time, and improved signal coordination. Even though vehicles travel a greater distance to make an indirect left turn through the crossover, this delay is offset by the reduced intersection delay to produce favorable results. The ideal location for a median U-turn is where high volumes on arterials conflict with moderate or low left-turn volumes and any cross street through-volumes. Several variations of this alternative could also be implemented.

Although the median U-turn is the most common alternative to the direct left turn, several other designs exist that may serve as alternatives. These include the jughandle, bowtie intersection, quadrant roadway, continuous flow intersection, superstreet, and paired intersections.

The jughandle design has been used by several states, New Jersey DOT being the main advocate. The jughandle does not require a wide median, but does require additional right-of-way for the ramps. Some agencies expressed concern over driver confusion associated with jughandles although confusion could be reduced if jughandles were used as the primary means for making turns through the arterial corridor. This option is best suited on arterials with high through-volumes, moderate-to-low left-turn volumes, and narrow right-of-ways.



1.4 Report Organization

Section 2 of this report contains an analysis of the study's survey results. Sections 3 and 4 address the operational and safety analysis of the project, respectively. These sections include the approach as well as the results. Section 5 presents the summary of findings from this study. Policy recommendations are contained in Section 6. Finally, the integration guidelines can be found in Section 7.



2. ANALYSIS OF SURVEY RESULTS

In early October 2001, a survey was sent to a representative from each state's transportation agency. Responses were received from twenty-five of the fifty states. The results of this survey are useful as a best-practices inventory. Table 1 shows the responses received to date. Table 1 does not include Florida DOT, which responded to our survey, but the information was obtained through personal communications and review of literature received from them.

Table 1. Summary of Survey Results for Restricting Left Turns

States Responding to Survey	Policy/Guideline for Restricting Direct Left Turns		Study Conducted to Evaluate Operational or Safety Effects		Policy/Guideline for Accommodating Deterred Traffic		Design Standards for Restriction and/or Accommodation of Deterred Traffic	
	Yes	No	Yes	No	Yes	No	Yes	No
Alabama		X		X		X		X
Arizona		X		X		X		X
Arkansas		X		X		X		X
Colorado	X		X			X	X	
Delaware		X		X		X		X
Indiana		X	X			X		X
Iowa		X		X		X		X
Kansas		X		X		X		X
Louisiana		X		X		X		X
Maryland		X	X		X		X	
Massachusetts		X		X		X		X
Michigan		X	X		X		X	
Minnesota	X		X			X		X
Missouri		X		X		X	X	
New Hampshire		X		X		X		X
New Jersey		X		X		X	X	
New York		X		X		X		X
Ohio	X			X	X		X	
Rhode Island		X		X		X		X
South Dakota	X			X		X	X	
Tennessee		X		X		X		X
Texas	X		X			X		X
West Virginia		X		X		X		X
Wyoming		X		X		X		X

Of the responses received, only the Colorado, Minnesota, Ohio, South Dakota, and Texas DOTs have implemented policies or guidelines that address the restriction of direct left-turns. Colorado has a regulation in place that addresses both new and existing roadways which is based on the access classification of the road. Minnesota is currently developing an access management manual that will address this issue. The Minnesota restriction will be based on traffic volumes, crash experience, type of through road, and distance from adjacent median openings, and will pertain to both new and existing facilities. Ohio and South Dakota also have guidelines for

restricting direct left turns, which are applicable to both new and existing roads. The bases for such restrictions in these two states are access point density, speed limit of the road, and type of road. Texas's guidelines also apply to new and existing roads, but an average daily traffic volume on the through road of 20,000 to 25,000 is the basis for the guidelines, specifically for the use of raised medians.

The majority of agency responses acknowledged their lack of formal policies or guidelines related to this topic. However, many states, such as Indiana, Michigan, and New Jersey, responded that while no formal policy exists, the DOT handles left-turn restrictions from driveways on a case-by-case basis based on traffic and geometric factors. The New Jersey DOT makes decisions on left-turn restrictions based on through-traffic volume, traffic volume from the adjacent facility, crash experience, sight distance along highways, and operational efficiency.

Table 2 summarizes the responses received from states regarding whether they have conducted recent studies on restricting left turns and accommodating the left-turn deterred traffic.

Table 2. Study Performed on Left Turn Restrictions

State Responding	Type of Study Performed, Responsible Party, Date	Elements of Study
Colorado	Colorado Access Control Demonstration Project, 1985	Safety and operational effects of medians
Florida	Safety impacts - completed Operational impacts - ongoing Both by Florida DOT and University of South Florida	Safety and operational impacts of direct left turn vs. right turn followed by U-turn
Indiana	Purdue University, 1997	Various forms of access control and tools
Maryland	JMT Consultants	Safety effectiveness of left turn restrictions
Michigan	Michigan DOT, December 1995	Directional crossovers, Michigan's left turn strategy
Minnesota	SRF Consulting, to be completed Dec. 2001	Access Management issues
Texas	Texas DOT, to be completed Sept. 2002	"Techniques for Managing Access on Arterials"

Many states have conducted studies or are aware of current studies related to this topic. A research project at Purdue University, in conjunction with the Indiana DOT, dealt with various forms of access control and access management tools. A "Guide to Directional Crossovers, Michigan's Preferred Left Turn Strategy" was developed in 1995 by the Michigan DOT to address the subject of restricting left turns. The Minnesota DOT is currently working with SRF Consulting of Minneapolis to study this topic. The Texas DOT is conducting a research project entitled "Techniques for Managing Access on Arterials," due to be finished in September 2002. The Maryland DOT contracted with JMT Consultants to evaluate the safety effects of restricting



the direct left turn. It was found that restricting direct left turns was successful in reducing angle crashes at driveway intersections and useful in places where signals should be avoided.

The Florida, Michigan and Ohio DOTs have a policy or guideline for accommodating the deterred traffic from the restricted left turn. These guidelines are used for both new and existing roads. Michigan's Guide to Directional Crossovers supports the accommodation of deterred traffic. In Ohio, left-turn deterred traffic is accommodated by the use of access roads, cross access to properties with full access, and access to adjacent streets. While the New Jersey DOT does not have a formal policy to accommodate left-turn deterred traffic, they encourage the use of U-turns on divided highways and jughandles on divided and undivided highways, especially with new construction. New Jersey also implements signalized jughandles for U-turns and left turns. The Florida DOT encourages indirect left turns rather than direct left turns. They have median opening standards for both directional-type openings where only left-ins are allowed and full median openings.

New Jersey requires all new developments to operate at a "non-failing" level of service (LOS) or above a LOS of F. If found that the failure is due to left turns, then the state recommends that the development either be downsized or access is restricted to a right turn only. If the left turn was to be restricted, the developer is then required to mitigate the impacts of the diverted trip at a location in the corridor where alternative routes are available. This concept could be applied in Ohio where a great deal of new development along major roadways contributes to poor performance of the roadway network.

Many states reported the need to address warrants for left-turn restrictions and median closures and the resulting U-turn movements in the next update of their access management manual. These states reported one or more of the following factors that should be considered in left-turn restriction warrants: through-traffic volume, traffic volume on the adjacent facility, access point density, crash experience, type of through-road, distance from adjacent median openings, and the feasibility of U-turns at the median opening.

On the issue of constraints to restricting left-turn movement from driveways, five states reported that business owners expressed concerns. Indiana has a relatively straightforward policy of implementing access restrictions to a new facility rather than removing existing access points. Missouri reported that in addition to the property owners' concerns, the additional right-of-way costs to provide alternatives for left-turn deterred traffic becomes a constraint in their efforts to restrict direct left turns.

The Indiana DOT found that access control measures are rarely popular with established property owners and/or businesses directly affected by the measures, but do not often cause a problem with access to new facilities. The Minnesota DOT observed that larger cities and counties support access management policy and regulation, but smaller communities are less likely to feel the need for the guidelines. This seems to stem from their focus on economic development. The South Dakota DOT's design standards are just beginning to be implemented and have not met any negative feedback from the public.

The survey results revealed that very few states have formal policies regarding restricting direct left turns from a development and accommodating the resulting turn movement. Instead, most



states handle this topic on a case-by-case basis. The most common factors influencing the decision to restrict a direct left turn movement are the through volume on the roadway and the crash experience at the site. In addition, several states realize the need for access management techniques and are in the process of studying and developing access management guidelines for their state. These states concluded guidelines need to address both new and existing facilities.



3. OPERATIONAL ANALYSIS

3.1 Data Collection

For this study, eight sites were chosen for evaluation, a combination of multi-lane divided, multi-lane undivided, and two-lane roads. These sites served as a representative sample of Ohio's state routes. Unsignalized driveways leading to major traffic generators, such as strip malls or super stores, which exit onto main roadways were additional study elements. Mainline speeds were between 35 to 45 mph. Table 3 summarizes the characteristics of each site.

Table 3. Summary of Site Characteristics

Main Road	Speed (mph)	No. of Lanes	Class	Driveway	Between	County
Alex Bell	35	4	Undivided	Cross Pointe Center	Far Hills and Loop Road	Montgomery
Lyons Road	45	4	Undivided	Walmart	SR 741 and Lyons Ridge Road	Montgomery
SR 725	45	4	Undivided	K-Mart	South Towne Center Drive and Kings Ridge	Montgomery
SR 741	45	4	Undivided	Contemporary Lane	Circuit City Drive and Prestige Plaza Drive	Montgomery
SR 725	45	4	Divided	Hooters Driveway	Paragon and Congress Park	Montgomery
West Broad	45	6	Divided	Westland Mall	Westland Mall Entrance and West Broad Plaza	Franklin
US 36	35	2	Undivided	Walmart, Kroger	SR 29 and Dugan Road	Champaign
US 22/SR 3	45	2	Undivided	Landen Square	Landen Drive and Columbia Road	Warren

Geometric, traffic flow, and control data were collected for each study site. Geometric data included intersection configuration (pocket lanes, lane alignment, etc.), lane width, number of lanes, lane channelization, width of medians, and driveway location and spacing. Traffic flow data included volume counts by movements, average speed, travel times, and turn prohibitions. Traffic control data included type (actuated, semi-actuated or fully actuated signals), cycle length and phase length for non-actuated controllers, and phase settings and locations of detectors for the actuated controllers. The study sites consisted of one or more driveways and the two signals at either end of the study site corridor.

Field data was collected on travel time in the study corridor and queue length at intersections to verify the simulation output with actual conditions. Travel time data was collected by driving a test vehicle at average speed in the corridor several times and queue length was computed by field observations at the intersections.

3.2 Methodology

Simulation models were developed for eight representative corridors consisting of two-lane and multi-lane (divided and undivided) roads. These were developed using the Federal Highway Administration (FHWA)'s Corridor Simulation (CORSIM) model. CORSIM is a detailed microscopic simulation model that has undergone years of testing and evaluation by the FHWA, and has shown a high degree of correspondence to actual flow conditions. Following

development, the models were carefully calibrated to ensure accurate representations of reality as verified by field data.

Average delay per vehicle was selected as the measure used to assess the impact of the alternative strategies and identify the threshold values used to select these strategies. Average delay per vehicle is a widely used measure of effectiveness in traffic engineering studies to evaluate operational performance.

Additionally, the networks were modeled using Trafficware's traffic signal optimization software, Synchro, to optimize signal timings for each alternative option, including U-turns at intersections and U-turns beyond intersections. The optimum signal timing for each alternative at each site was then input into the appropriate CORSIM model to effectively measure delays and average speeds. The safety analysis performed will be addressed in Section 4.

3.3 Alternatives to Direct Left-Turn

Based on the assessment survey results, literature review, and input from the research team, four alternatives (cases 1,2,3 and 4) to the direct left-turn were evaluated. Figure 1 shows Case 1, a driveway schematic with the permitted left-out to arterial, left-in from arterial, right-in from arterial, and right-out to arterial.

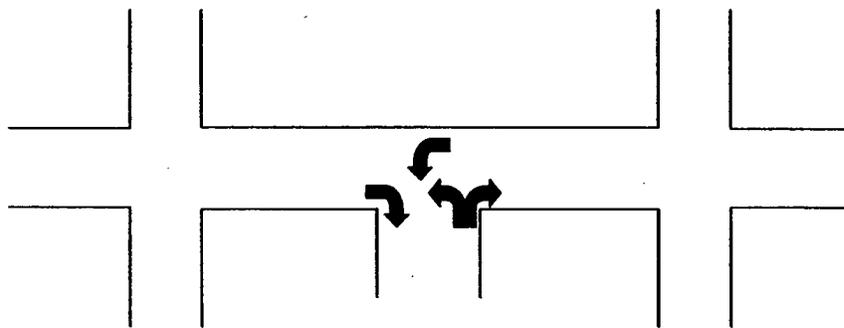


Figure 1. Case 1 - Existing Condition

For Case 2, shown in Figure 2, left turns are restricted with a right-in/right-out island and left-turn deterred traffic is forced to make a U-turn at the next intersection.

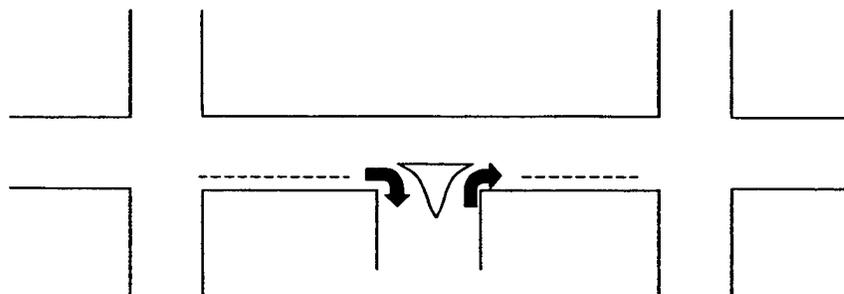


Figure 2. Case 2 - U-Turn at Intersection



In Case 3, left turns at a driveway are eliminated by design (such as providing a right-in/right-out only island) and/or signs. In many instances, although traffic volume may justify signalization, driveways cannot be signalized due to their proximity to the next signal. Figure 3a illustrates Case 3a with the U-turn beyond the next intersection. Figure 3b illustrates Case 3b with the U-turn placed before the intersection. U-turns are usually permitted 600 to 660 feet before or after the nearest intersections.

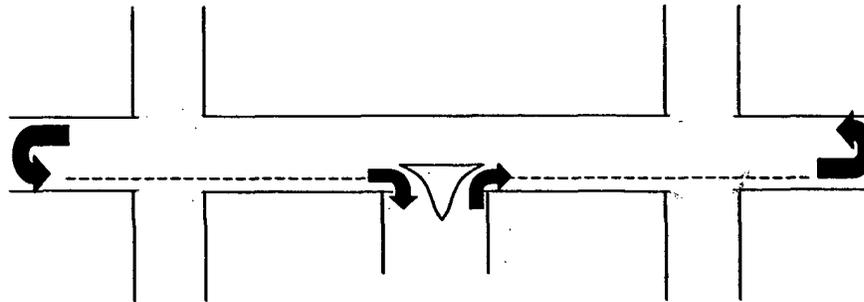


Figure 3a: Case 3a - U-Turn beyond Intersection

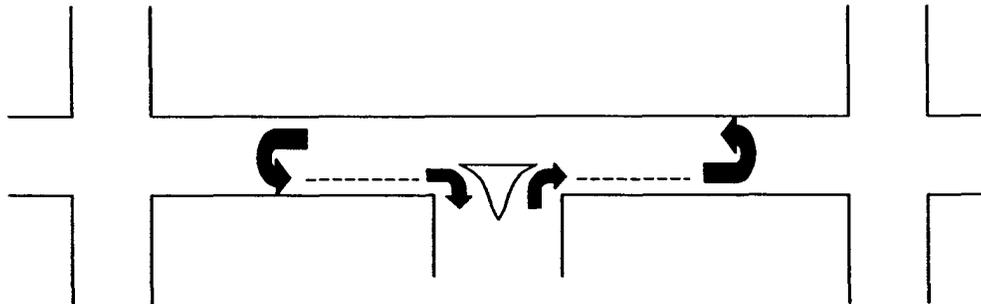


Figure 3b: Case 3b - U-Turn before Intersection

In case 4, the jughandle (shown in Figure 4), ramps located before the intersection diverge from the right side of the arterial to aggregate all turns from the arterial into the jughandle.

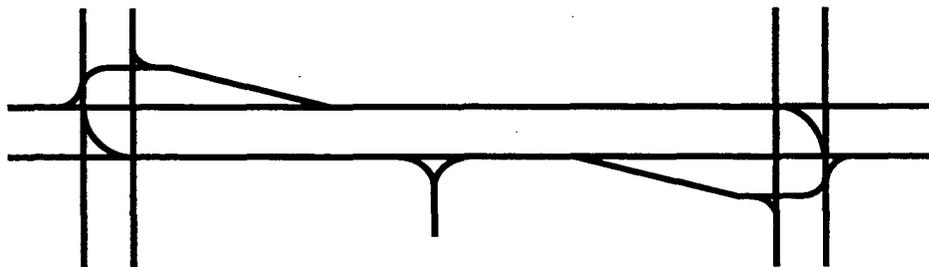


Figure 4. Case 4 - Jughandle Design

Traffic desiring to make a left turn out of the driveway would be forced to proceed to the next signalized intersection, follow the jughandle, and make a direct left turn at the signal. The ramps are typically STOP-controlled for left-turns and YIELD-controlled for right turns. The ramp terminals should be located several hundred feet from the main intersection, preventing blockage from queues from the signal on the cross street.



3.4 Data Analysis

The analysis focused on the arterial and driveway volumes in determining the effects of restricting direct left-turns and providing alternative movements. The study examined the relative impacts of each of these factors on the operational performance of different left turn alternatives and to what level.

3.5 U-Turn Alternatives

This study evaluated three major operational strategies for all sites:

Case 1: No restriction of direct left turns from or to driveways,

Case 2: No direct left turns in or out of driveways and diverted traffic makes a U-turn at the next intersections, and

Case 3: No direct left turns in or out of driveways and diverted traffic makes a U-turn at mid-block. A mid-block U-turn refers to a U-turn either before or after the next signalized intersection depending on the distance between the driveway and closest intersections.

First, the existing condition (Case 1) was modeled and evaluated. Next, the network was modeled for Case 2 allowing only right-in, right-out traffic at the driveway and allowing U-turns at the next signalized intersection. Finally, Case 3 was modeled by allowing only right-in, right-out traffic at the driveway and providing mid-block U-turns before or beyond the next signalized intersections. Each network was simulated with CORSIM to compute the delay per vehicle for various cases that were considered in this study.

3.5.1 Impacts of Changes in Mainline Volume

Figure 5 shows the changes in total network delay with the increase in the mainline volume at multi-lane divided sites.

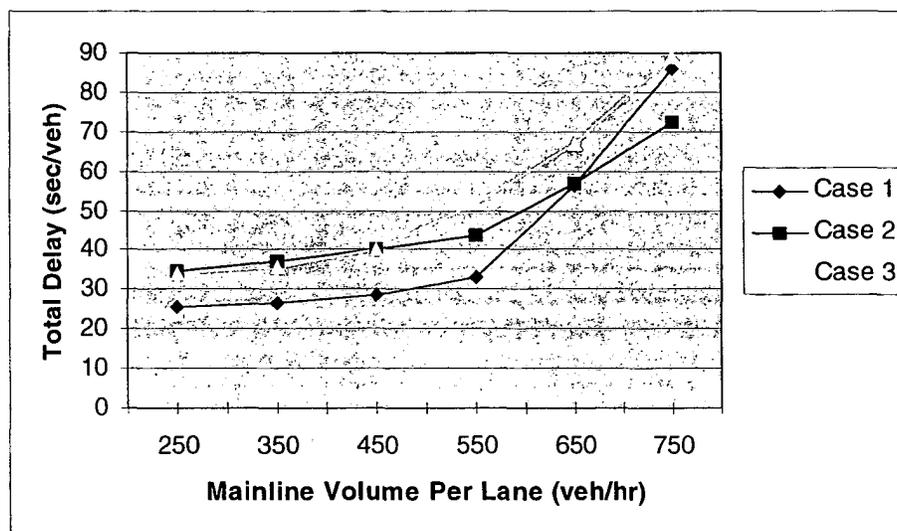


Figure 5. Average delay at different mainline volumes per lane at multilane divided sites

1

2

3

4

5

6

The driveway volume was kept constant with the changes in the mainline volume. As shown in the figure, Case 1, where no restrictions on left turns were implemented, operationally outperformed the cases with left turn restrictions at the driveways as long as the mainline volume per lane was less than 650 vehicles per hour. Case 2 becomes the preferred alternative after the volume threshold of 650 vehicles per hour per lane is reached.

Figure 6 shows the changes in total network delay with increases in the mainline volumes at multi-lane undivided sites. As shown in Figure 6, Case 1, with no restrictions on left turns, and Case 3, with a mid-block U-turn were almost equal in operational performance, as long as the mainline volume per lane was less than 450 vehicles per hour per lane. Case 1 was the preferred alternative once the volume threshold of 450 vehicles per hour per lane was achieved.

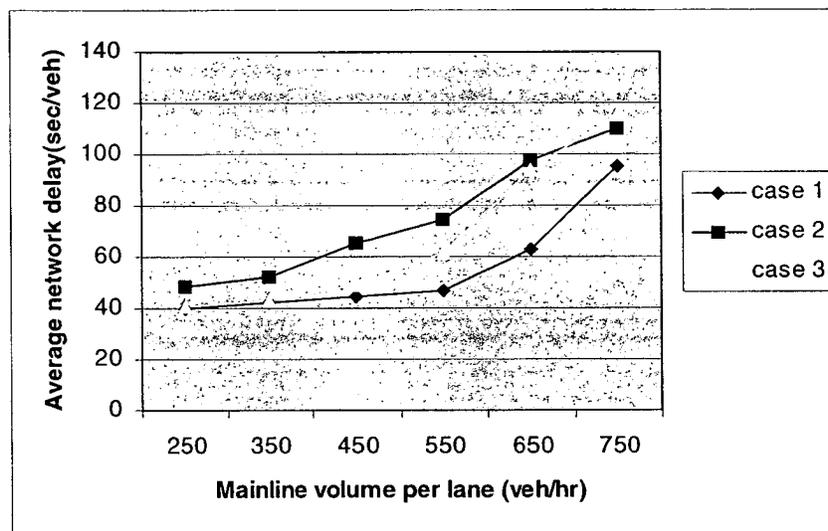


Figure 6. Average delay at different mainline volumes per lane at multilane undivided sites

Figure 7 shows the changes in total network delay with the increase in the per-lane volume on two-lane roads.

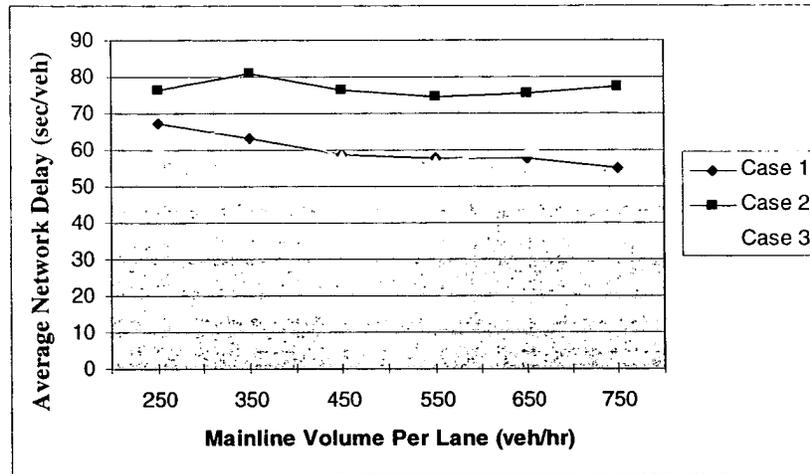


Figure 7. Average delay at different per-lane mainline volumes on two-lane road sites

As shown in Figure 7, Cases 1 and 3 performed similarly at different volumes. Case 1 performed slightly better after the volume threshold of 650 vehicles per hour per lane. Overall Case 2 performed at an inferior level as compared with Cases 1 and 3.

3.5.2 Impacts of Driveway and Mainline Volumes

Figures 8, 9 and 10 show a graphical representation of the total driveway volume versus average network delay for a multi-lane divided site (Hooters Drive), for Cases 1, 2 and 3, respectively. As shown in the figures, **an increase in mainline volume plays a greater role than an increase in the driveway volume in terms of total network delay.** When the driveway volumes were changed to 50, 100, and 200 vehicles per hour for a fixed mainline volume, the change in delay was minimal, however when the mainline volume was increased to 500, 850, and 1200 vehicles per hour per lane, the delay was greatly increased. Similarly, Figures 11, 12 and 13 show a graphical representation of a multi-lane undivided site (K-Mart Drive), for cases 1, 2 and 3, respectively. These figures also show similar results as the multi-lane divided site, where changes in driveway volume had minimal effect on average delay compared to the changes in mainline volume.



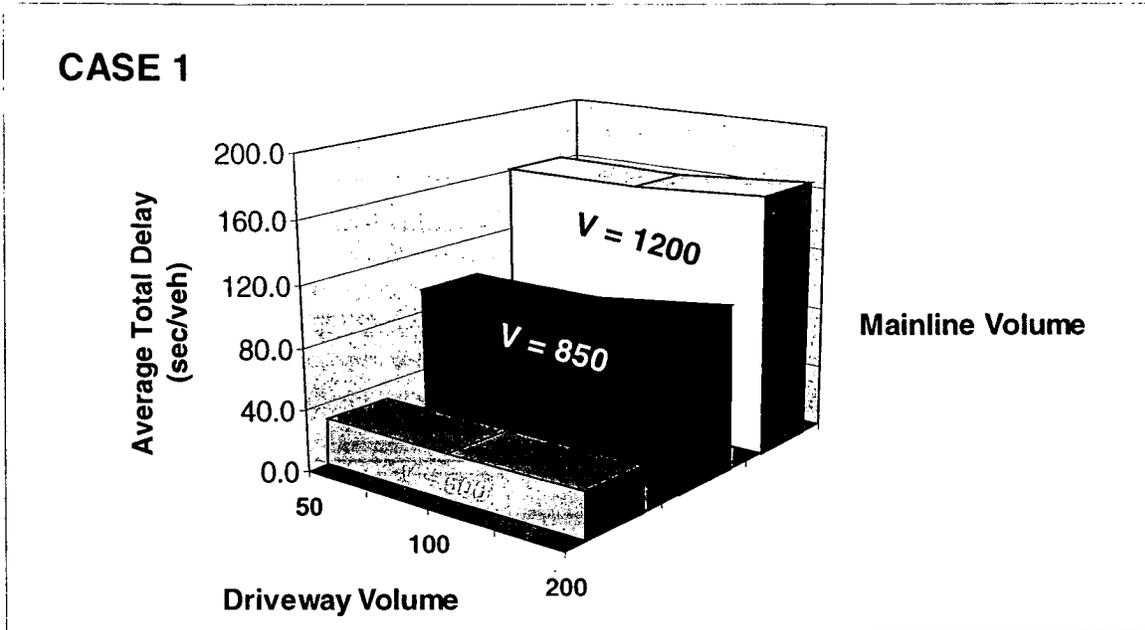


Figure 8. Driveway Volume vs. Delay for Multilane Divided (Hooters Drive case 1)

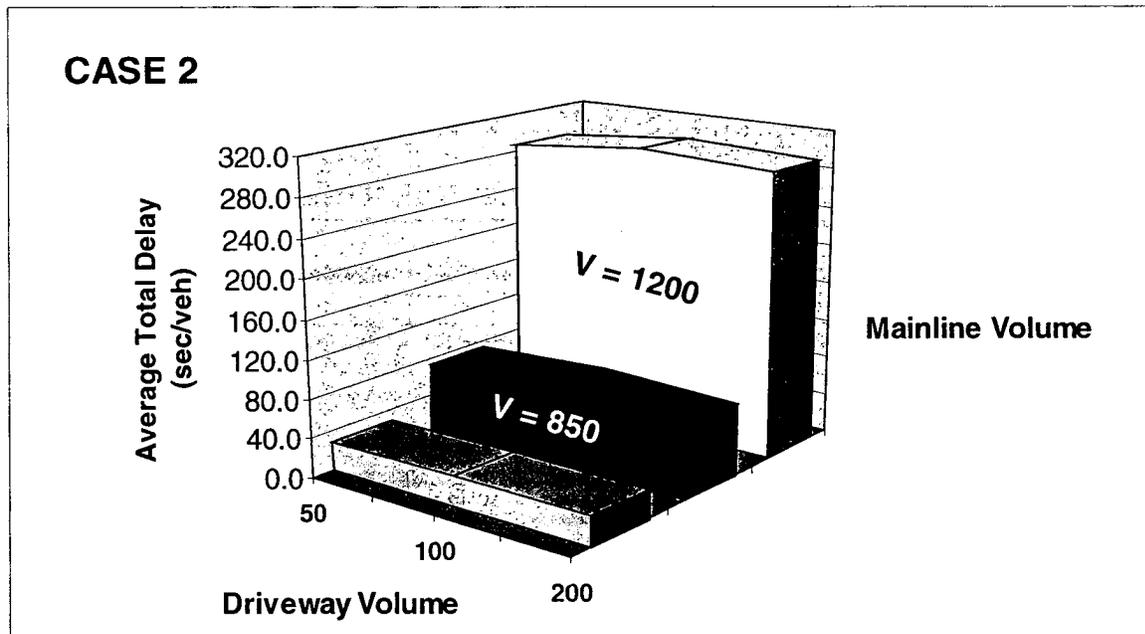
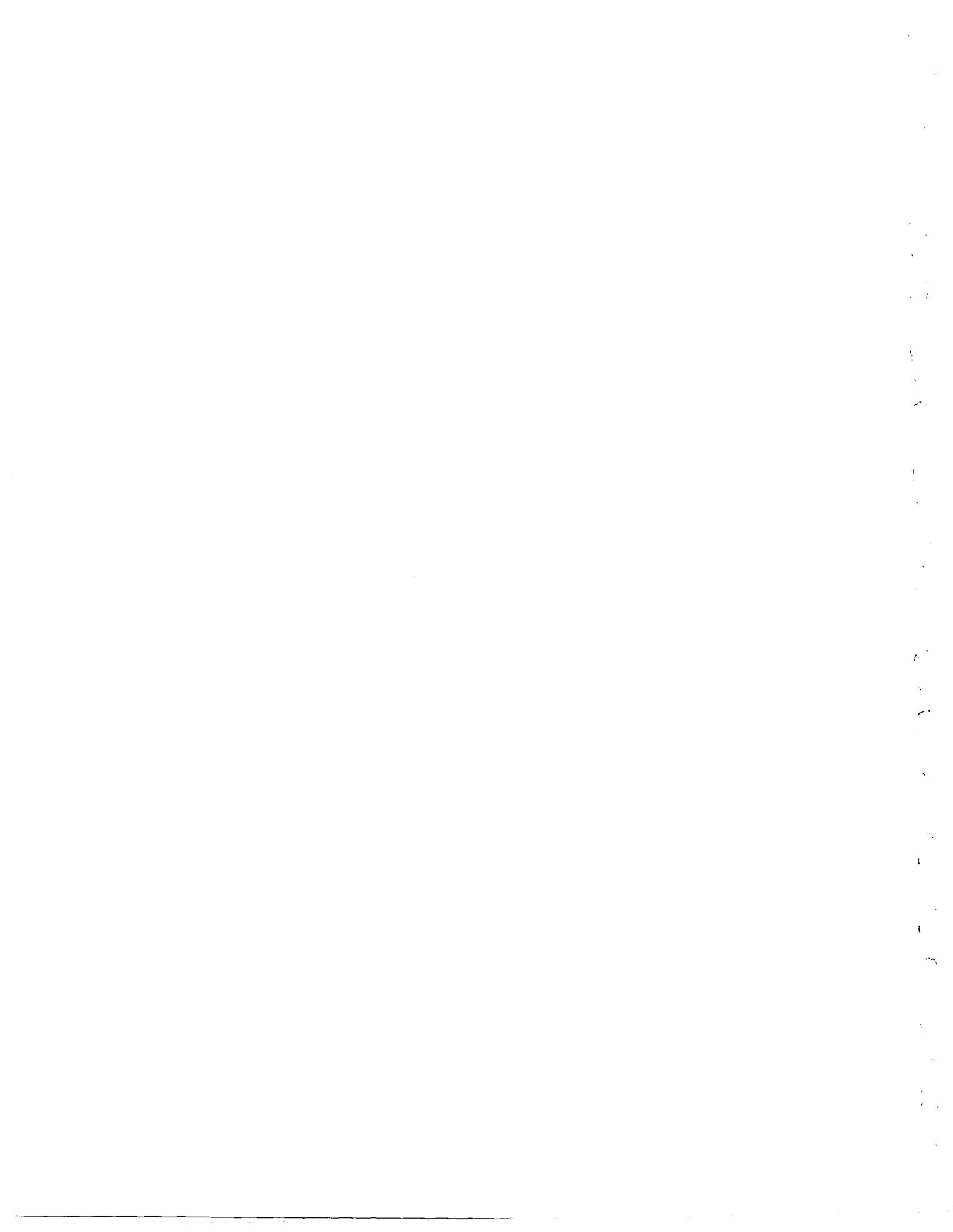


Figure 9. Driveway Volume vs. Delay for Multilane Divided (Hooters Drive case 2)



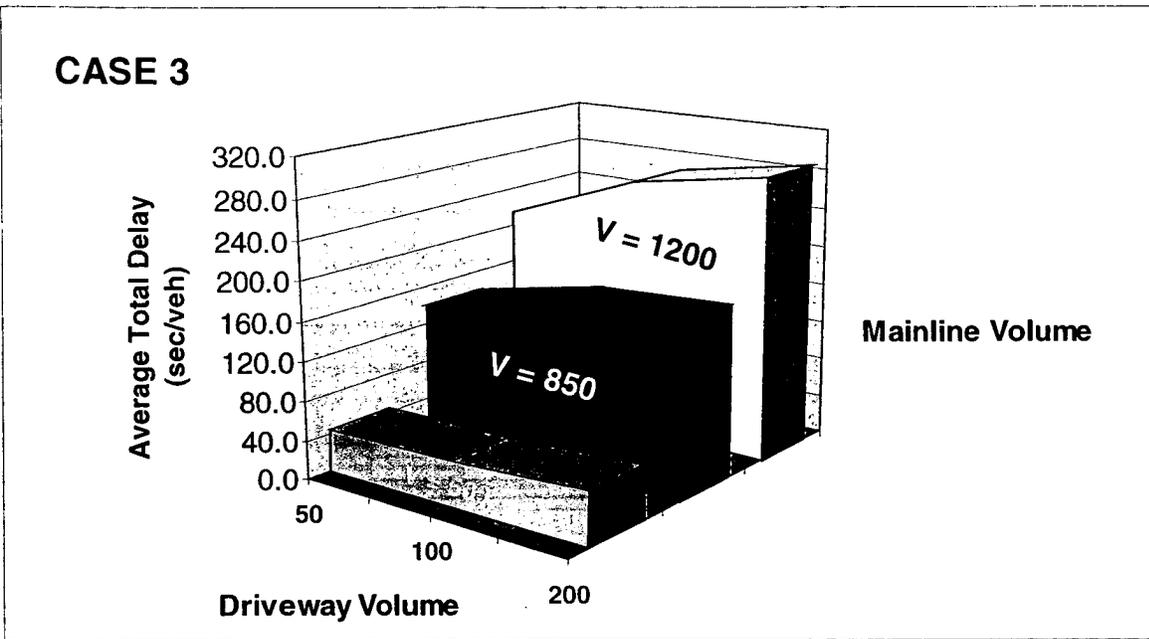


Figure 10. Driveway Volume vs. Delay for Multilane Divided (Hooters Drive case 3)

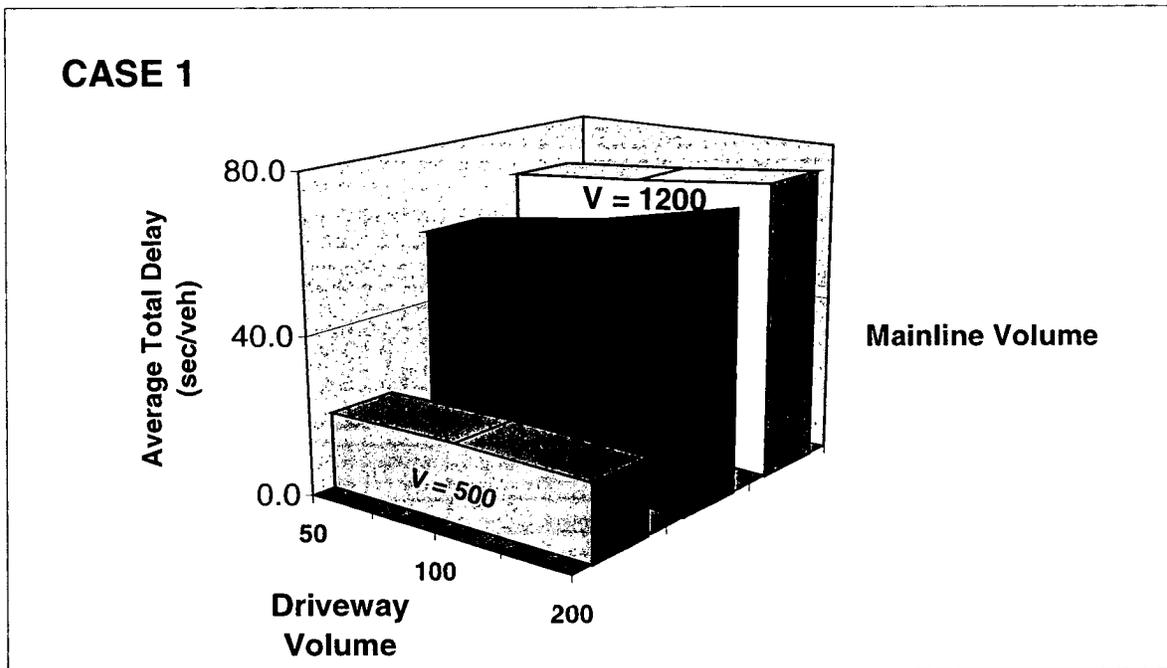


Figure 11. Driveway Volume vs. Delay for Multilane Undivided (K-Mart Drive case 1)

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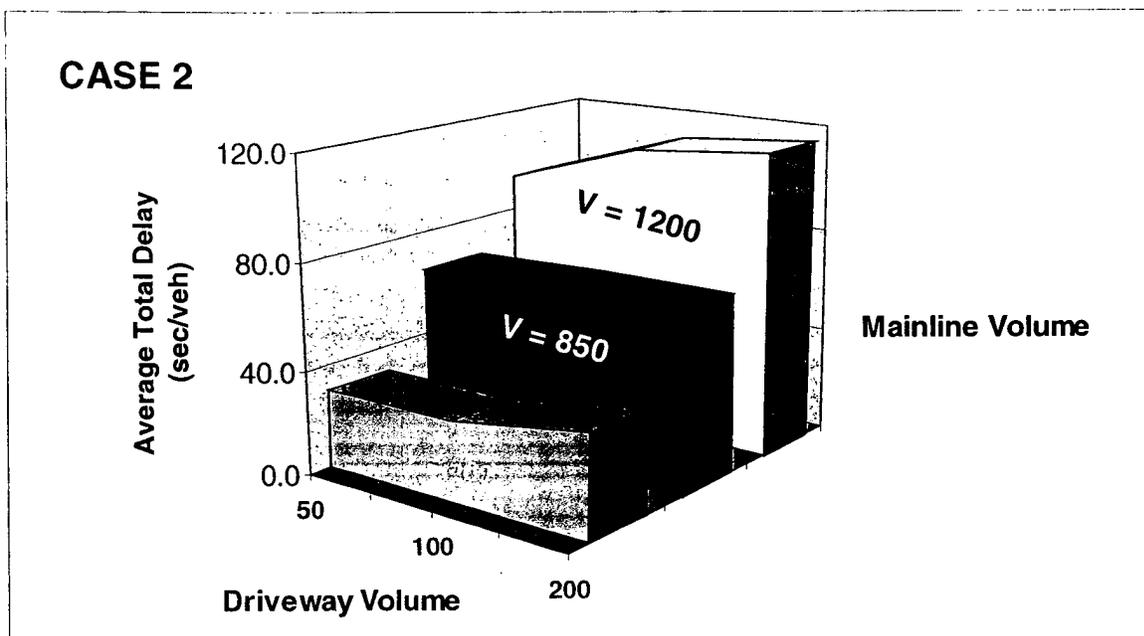


Figure 12. Driveway Volume vs. Delay for Multilane Undivided (K-Mart Drive case 2)

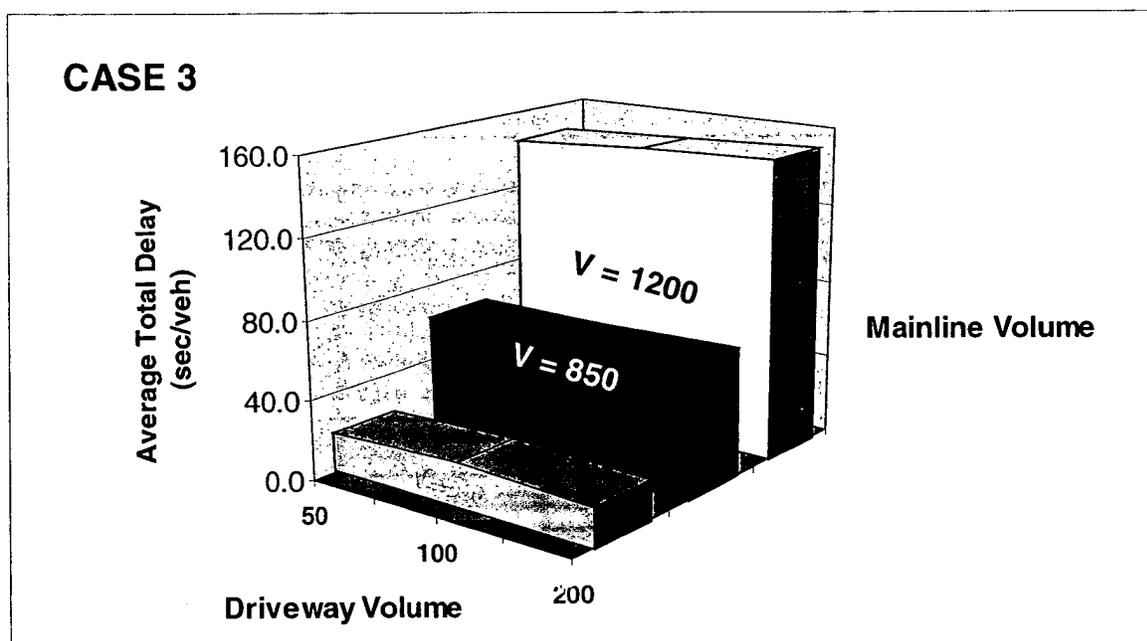
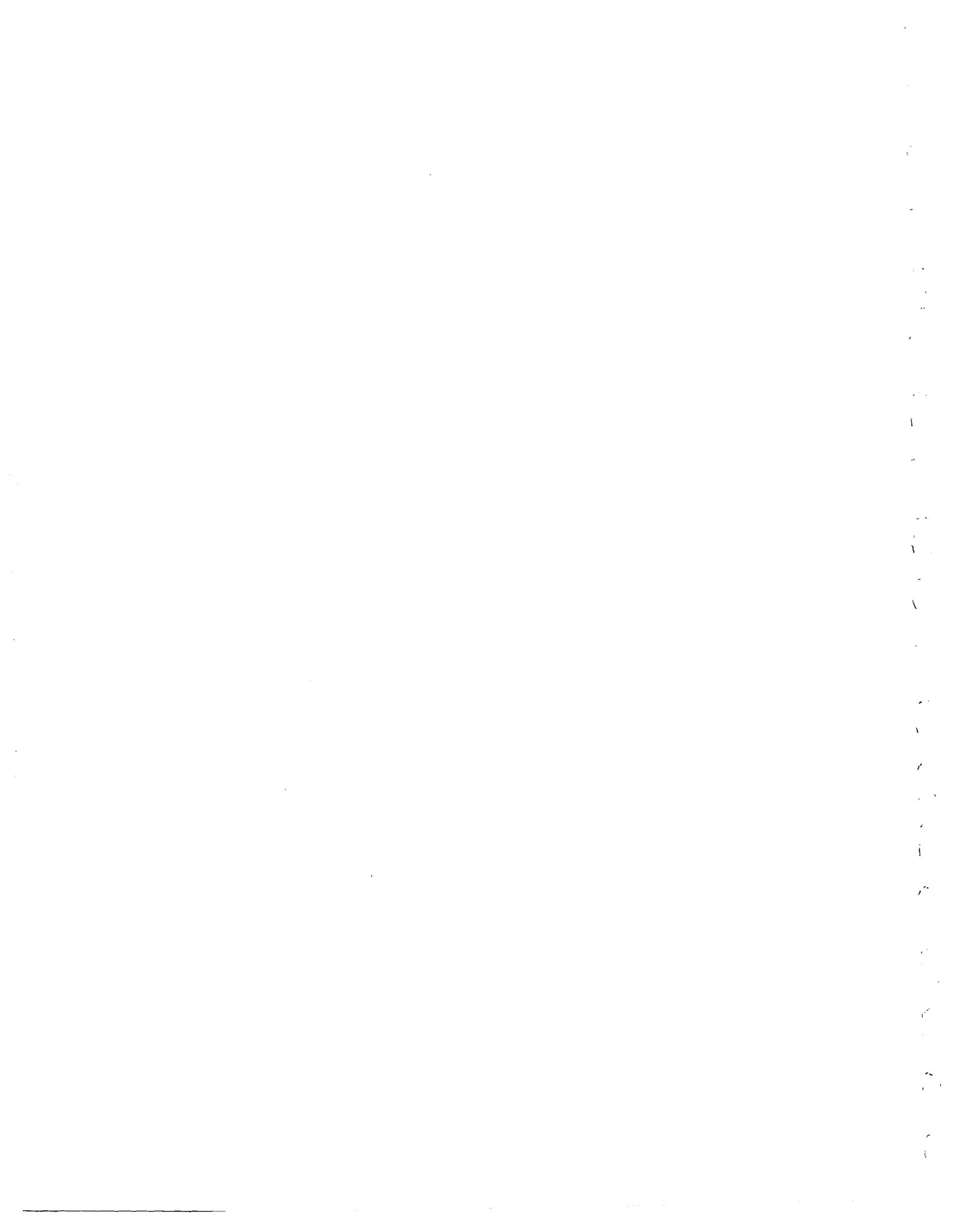


Figure 13. Driveway Volume vs. Delay for Multilane Undivided (K-Mart Drive case 3)



For the multi-lane divided site, case 1 (no restriction) and case 2 (restriction and U-turns at intersections) appear to be the preferred operational strategies, depending upon the mainline volume. For low (500) and medium (850) mainline volumes per hour per lane, case 1 and case 2 performed equally. For high (1200) volumes per lane, case 1 is preferred. In addition, the ranking of the strategies appear to be much more sensitive to mainline volume than to the ratio of the driveway to mainline volume. For multi-lane divided, case 3 (restriction and U-turn at mid-block before or after intersection) does not appear to be a desirable strategy.

For the multi-lane undivided site, case 1 (no restriction), case 2 (restriction and U-turns at intersections) and case 3 (restriction and U-turn at mid-block before or after intersection) appears to perform in a similar fashion to low (500) and medium (850) mainline volume. Case 1 is the preferred alternative for high (1200) volume.

3.6 Other Alternatives

Two additional cases were evaluated. Case 4 is a jug handle design at the intersection to accommodate left-turn deterred traffic. Case 5 allows no direct left turns in or out of all-but-one driveway. This unrestricted driveway is signalized and left-turning traffic from the other driveways must use internal circulation routes to move to the signalized driveway and make a concentrated direct left turn.

3.6.1 Case 4 - Jughandle

Jughandles were evaluated in light of the three original U-turn alternatives (Case 1, Case 2, and Case 3) discussed above for a multi-lane divided, a multi-lane undivided and a two-lane road. Figures 14, 15, and 16 compare the average delay for a multi-lane divided site, a multi-lane undivided site and a two-lane road site, respectively.

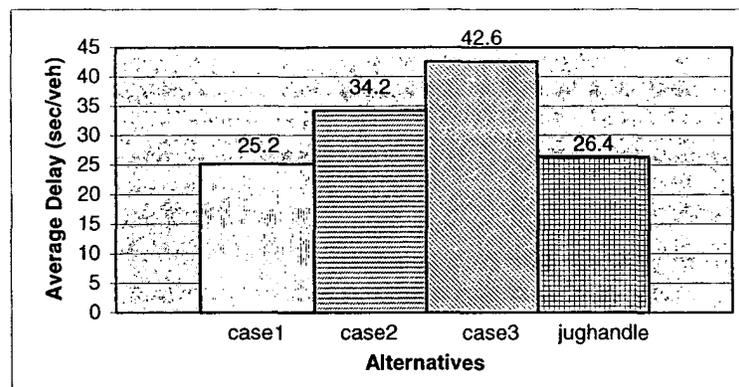
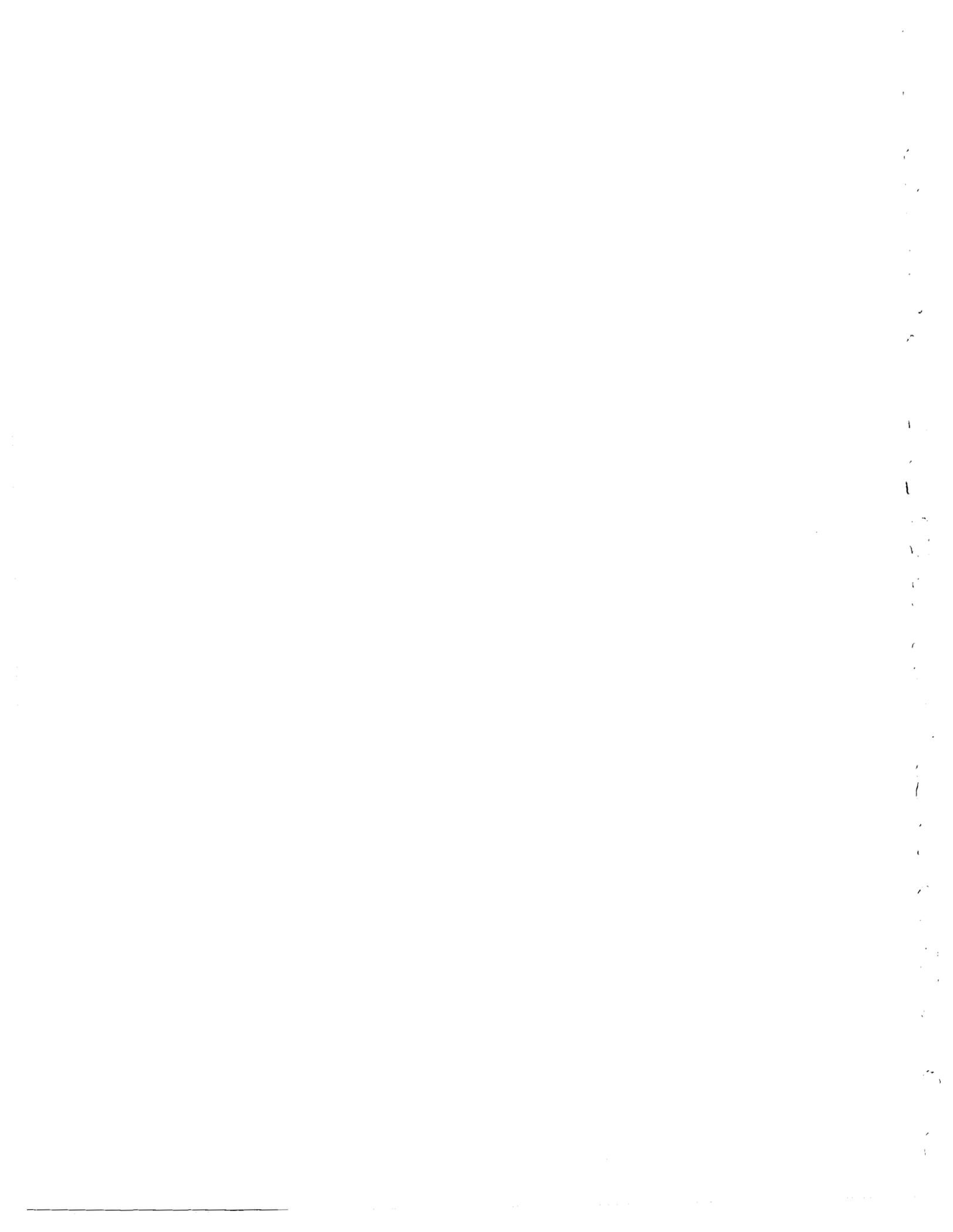


Figure 14. Delay per Vehicle for Three Cases and Jughandle for Multi-lane Divided



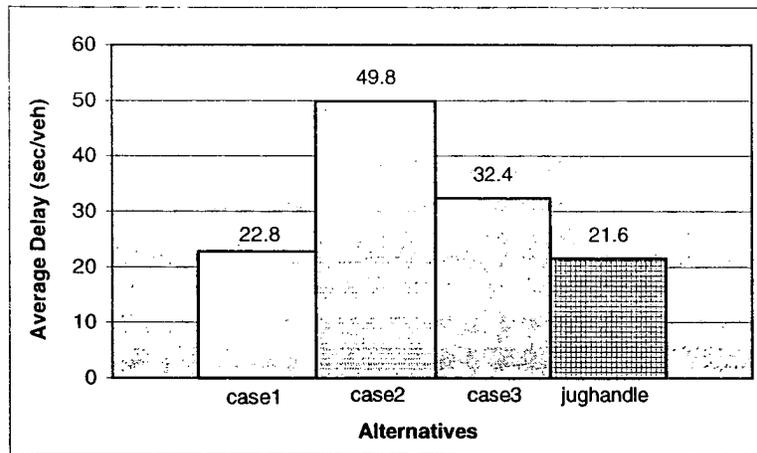


Figure 15. Delay per Vehicle for Three Cases and Jughandle for Multi-lane Undivided

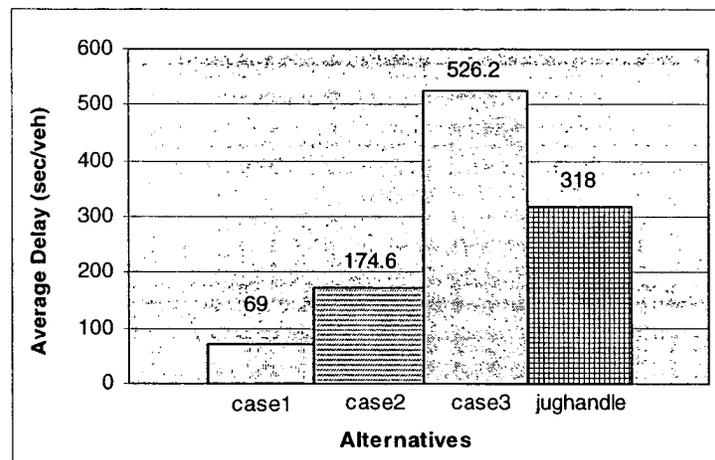


Figure 16. Delay per Vehicle for Three Cases and Jughandle for Two-lane Rural Roads

The jughandle result was slightly inferior to Case 1 for multi-lane divided roadways, shown in Figure 14. As shown in Figure 15, the performance of the jughandle was superior to the other three alternatives for multi-lane undivided highways. For two-lane roads (Figure 16), Case 3 and the jughandle did not perform well due to the high volume of opposing traffic. Since the existing volume at the two-lane site was much higher than the volume threshold shown in Figure 7, the operational performance of the alternatives was worse than the existing condition of no restrictions on the left turn.

Existing high volume to capacity ratios at the nearest signalized intersection negatively impacted the alternatives for two-lane roads where additional demands are placed on signal capacity. For multilane divided and undivided conditions, one important factor is the volume to capacity ratio of the nearest intersections. When the volume at the intersection is near or above the capacity, significant delay already exists, in turn causing the implementation of any U-turn alternatives to perform negatively, as it will impart additional burden on the intersection capacity.



3.6.2 Case 5 - Concentrated Left-Turn

Figure 17 shows one of the multi-lane undivided study sites where the concentrated left-turn strategy was evaluated.

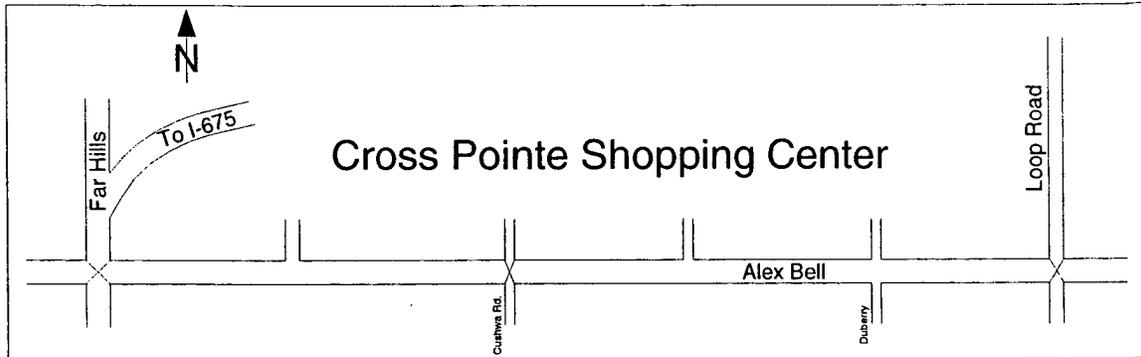


Figure 17. Alex Bell Site Diagram

This site contains four driveways between two intersections: Alex Bell and Far Hills, and Alex Bell and Loop Road. The site contains three unsignalized drives and one signalized drive. The scenario restricted all left turns from all driveways except the Cushwa Road driveway, which is signalized. Under this scenario, all left-turn restricted traffic from the three other driveways was redirected to the Cushwa Road driveway and could then make direct left turns at this signalized driveway. This operational strategy performed the best compared with three other alternatives: Case 1, no restriction of left turns at the other driveways, Case 2, restricted left turns on driveways with U-turns provided at the next intersection for the left-turn-deterred traffic, and Case 3, restricted left turns on driveways with mid-block U-turns.

As shown in Figure 18, as compared to the other original cases, the concentrated left-turn strategy proved to be a beneficial alternative.

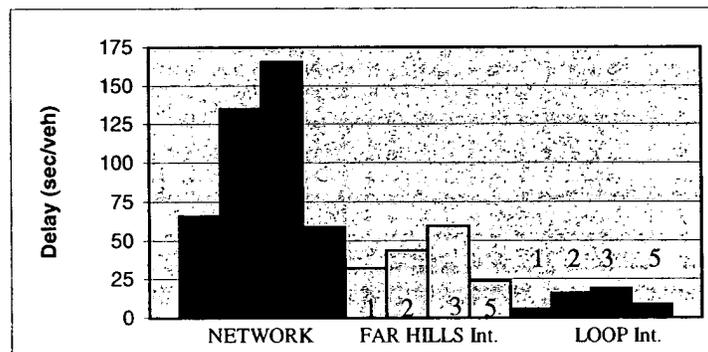


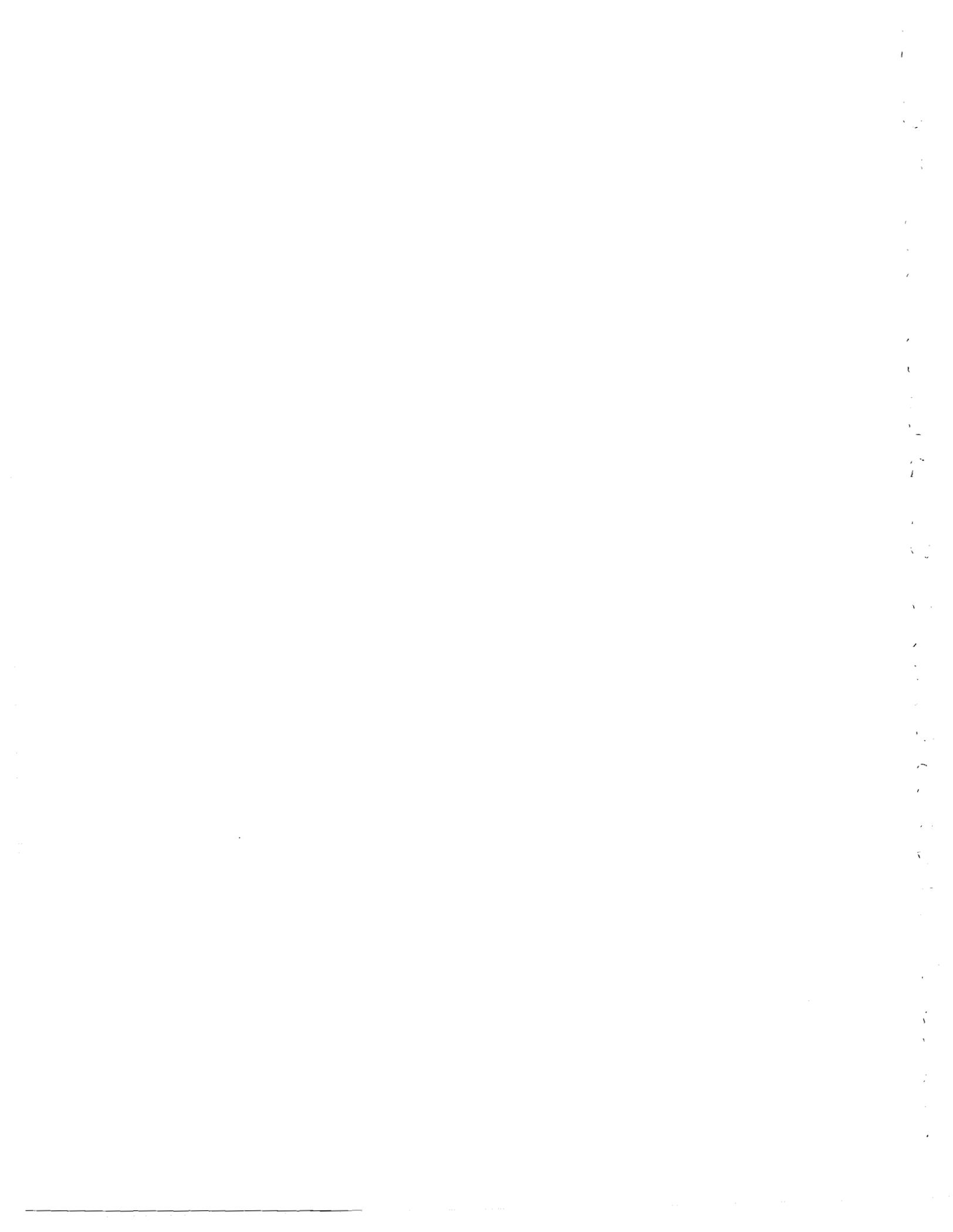
Figure 18. Operational Impacts of Various Strategies on Alex-Bell Road

Notes:

- Case 1 - No restriction of direct left-turn
- Case 2 - Left-turn restriction at the driveways and diverted traffic make U-turn at the next intersection
- Case 3 - Left-turn restriction at the driveways and diverted traffic make U-turn beyond intersection
- Case 5 - Concentrated left-turn at signalized intersection

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Where multiple driveways exist, restricting direct left turns from all but one driveway and allowing this traffic to make direct left turns at this signalized intersection may be operationally advantageous and more cost effective than the original three cases.



4. SAFETY ANALYSIS

The safety analysis for this project consisted of three parts: an analysis of crashes and crash rates at the current sites, review of published studies performed by other states, and communication with other state agencies.

4.1 Data Collection

Crash data covering a three-year period was collected for each site. The most current crash data available for ODOT, local government, and law enforcement officials was obtained for each site and used for analysis. Table 4 shows each site, the specific years of data collected, and where the data was obtained.

Table 4. Crash Data Characteristics

Type of Site	Multi-lane Undivided				Multi-lane Divided		2-Lane	
Site	Lyons	Alex Bell	SR 725	SR 741	SR 725	West Broad	US 36	US 22
Years of Crash Data	1997-1999	1998-2000	1999-2001	1999-2001	1999-2001	1999-2001	1999-2001	1999-2001
Data Collected From	ODOT	City Engineer Report	Crash Reports	Crash Reports	Crash Reports	ODOT	Crash Reports	Crash Reports

4.2 Methodology

From the crash data individual crashes were plotted and then categorized by type: rear end, sideswipe, angle, and left-in/left-out at each of the driveway sites. Left-turn crash rates per million vehicles entering the un-signalized driveway intersection were computed for each site.

4.3 Analysis of Existing Conditions

As described in the previous section, eight sample sites were selected representing: multilane undivided, multilane divided, and two-lane roads. Table 5 summarizes relevant crash data.

Table 5. Sample Sites Crash Summary

Type of Site	Multi-lane Undivided				Multi-lane Divided		2-Lane	
Site	Lyons	Alex Bell	SR 725	SR 741	SR 725	West Broad	US 36	US 22
Left Turn Crash Percentage (Left Turn Crashes/Total Crashes)	50%	15%	26%	11%	40%	21%	40%	100%
Left Turn Crash Rate (# Crashes per Million-Entering Vehicles)	49	25	101	16	113	54	125	58

The left-turn crash percentage is a measure of the number of crashes resulting from vehicles making left-turn movements into and out of the driveway divided by the total number of crashes at the driveway location. The crash rate is a measure of the amount of crashes related to vehicles making left-turn movements into and out of the driveway divided by the total number of vehicles



entering the driveway-mainline intersection. At many sites, the left-turning crashes represented a high percentage of the total number of crashes, indicating the value of reducing the number of left-turning vehicles at un-signalized driveways.

4.4 Expected Impacts

Due to the lack of study sites in Ohio, other states were contacted about their findings on the impacts of restricting left-turns and providing alternative movements to the left-turn deterred traffic. Additionally, recent studies were reviewed to estimate expected reduction in crashes.

A conflict is a point where two vehicle paths cross. Figure 19 shows conflict points on a two-lane road at an un-signalized driveway with no-turn restrictions.



Figure 19: Conflict Points at a Non-restricted Driveway (Two-Lane)

As shown in the figure, with all permitted turns from the driveway, a total of nine conflict points exist. Figure 20 shows the driveway with right-in right-out restriction and a mid-block U-turn.



Figure 20: Conflict Points at a Restricted Driveway with mid-block U-turn (Two-Lane)

A similar situation can be seen for a multi-lane road. Figure 21 shows the no restriction case, while Figure 22 illustrates a restriction on the direct left turn plus a U-turn movement.





Figure 21: Conflict Points at a Non-restricted Driveway (Multi-lane)

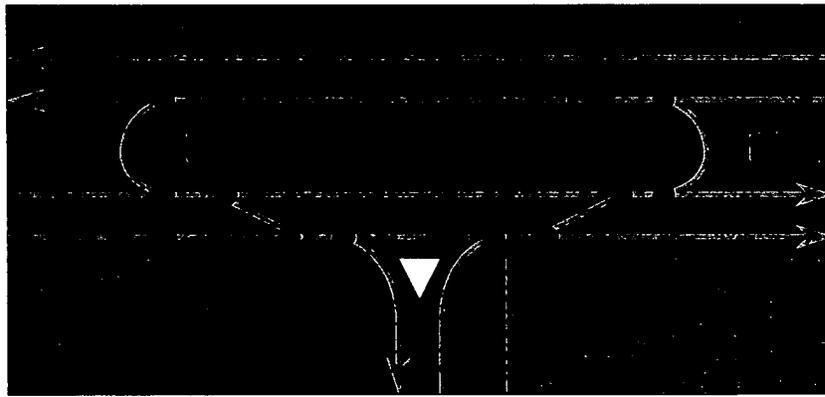


Figure 22: Conflict Points at a Restricted Driveway with mid-block U-turn (Multi-lane)

Without the direct left in and left out, conflict points are reduced, especially on a two-lane road. Limiting the conflict points and also separating them improves safety, by eliminating the risk of crashes from direct left in and left out option.

Recent studies which used actual conflict evaluation (observation of conflict-related measures) between direct left-turn and right-turn followed by a U-turn found reductions in actual conflicts in the field. The primary conflicts caused by the direct left-turn include the conflicts with the two-direction major road traffic and conflicts with all other movements at the median openings for the driveway. In the case of direct left-turns, drivers may get impatient and aggressive with a long waiting delay and move to the median opening without yielding to the major road through traffic or left-turning traffic.

The Colorado Access Control Demonstration Project of 1985 examined the safety and operational benefits of medians. It reported to the US Congress that the benefits of median use are excellent and crash rate increases as a result of U-turn movements in these corridors are minimal or nonexistent. In order for the U-turn movement to remain operationally safe, however, it must be combined with a strong supporting local street system. Poor supporting local street systems cause poor circulation and force motorists to make unusual, often unsafe, and even illegal movements to allow drivers to get where they want to go.

An access management paper published by the Florida DOT stated that their most recent research showed that by encouraging right turns followed by U-turns, the total crash rate was reduced by 18 percent and the injury crash rate was reduced by 27 percent (Florida DOT, Access Management Balancing Access and Mobility). The paper also acknowledged a strong relationship between access points per mile and crash rate. By increasing the spacing between access points through the use of right-in/right-out driveways with median U-turns, conflicts were reduced, in turn causing fewer collisions.

A Florida DOT sponsored study found that direct left turns led to more conflicts than right turns followed by U-turns (Dissanayake 2002). The site characteristics included: that the route was a major arterial, the roadway maintained three to four lanes in each direction and the speed of the roadway was at least 45 mph or higher. This study found that traffic conflicts were significantly reduced for a site where a direct left turn from a driveway was converted to a right turn followed by a U-turn. The author also compared the average number of crashes and crash rates and found that right turns followed by U-turns are much safer for high volume, multi-lane, major arterials.

Another study compared the safety effects of right turns followed by U-turns and direct left turns (Xu 2001). The author collected data for 258 sample sites within three Florida counties. These sites were selected based on the following criteria:

- Major urban or suburban arterial road, with four, six, or eight lanes, and with raised medians
- Large main road volume of 34,000 or more vehicles per day
- Key commercial or residential land use developments
- Selected driveways with sufficient driveway egress volume
- Sufficient median opening width ranging from 25 to 40 feet
- Posted speed limit between 40 and 55 mph on the arterial road
- Driveways that have direct access from abutting properties, no angle curb or parallel parking along the main road, and arterial segment length of the sites selected range from 0.1 to 0.25 miles.

This study found that for 6-lane divided arterials with large traffic volumes, high speeds, and high driveway/side street access volumes, the implementation of a right-turn followed by a U-turn compared to a direct left turn from a roadside facility led to a statistically significant reduction in total and injury/fatality crash rates, computed as 26.4 percent and 32 percent, respectively. For 8- and 4-lane arterials, implementing a right-turn followed by a U-turn compared to a direct left turn did not yield a statistically significant result due to small sample size.

No before-and-after study on actual crash reduction related to the implementation of the U-turn and jughandle was conducted for this study, due to the lack of sites for analysis. Safety impacts were evaluated based on the survey and communication with other state agencies that have evaluated the safety impacts of these alternatives in published reports. One issue that must be noted is that when the left-turning volume is shifted from the driveway to a U-turn at the nearest intersection, additional conflicts may be incurred between the U-turn vehicles and the opposing

right-turn vehicles. Therefore, restrictions should be placed on the opposing “right-turn-on-red” movement to eliminate these conflicts.

Although operational analysis provided mixed results for the U-turn alternatives, recent studies suggest a positive safety impact from implementing U-turns at intersections or at mid-block. The roadway characteristics that would have the most potential for improved safety through the restriction of left-turns and the provision of mid-block or intersection U-turns are listed below:

- Corridors in a major commercial or residential development
- Speed limit between 40 to 55 mph
- Major arterials – 4, 6 or 8 lanes
- ADT 30,000 to 40,000

4.5 Potential for Future Safety Study

Due to lack of appropriate sites in Ohio, it was not possible to perform a before and after study to evaluate the safety impacts of restricted direct left turn access. However, one site allowing right-in/right-out only access is currently under construction in ODOT’s District 2 in northwest Ohio. This site is a section of US 20 in Perrysburg, east of the I-75 interchange. Construction is under way to restrict direct left turns and encourage U-turns at the intersections. This site could be used to evaluate the safety effects of restricting the direct left turns.

Mid block U-turn bays has been installed on another section of US 20, between the City of Toledo/City of Maumee Corporation boundary and Glendale Avenue in Toledo. This section of the roadway was expanded from two-lanes to four-lanes with mid-block U-turn bays in the mid 1970’s. As a result of the dramatic geometric changes in the section, before and after data would not be comparable. Performance of this section of road has been very successful with crash rates continuing to be low and delay is minimal. Therefore, consideration should be given to using right-in/right-out restrictions followed by U-turn movements where conditions support.

5. SUMMARY OF FINDINGS

Although many alternatives are available to accommodate left-turn deterred traffic, the challenge is to identify the alternative(s) that are practical for Ohio's roads and highways, based on traffic and geometric conditions, especially considering the availability of right-of-way for existing roads. Many factors must be considered before making a decision to use an alternative to a direct left turn. Often, right of way constraints may force several alternatives to be discarded. Using the same amount of land to provide cross easements and private service roads may provide a better overall solution.

The survey results revealed that very few states have formal policies restricting direct left turns from a development and accommodating the resulting U-turn movement. Instead, most states handle this topic on a case-by-case basis. The most common factors influencing the decision to restrict a direct left turn movement are the through volume on the roadway and crash rates at the site. In addition, several states understand the need for access management techniques and are in the process of studying and developing access management guidelines for their state. These states have concluded that these guidelines need to address both new and existing facilities.

Currently, Ohio has guidelines for restricting direct left turns based on access point density, speed limit of the road, and the type of road. However, the deterred traffic is accommodated through the use of access roads, cross access to properties with full access, and access to adjacent streets. While, these measures have been in place for some time, there is a need for specific policies and guidelines to address this topic.

Very little operational difference was found between the no restrictions on direct left turns alternative versus restrictions with the U-turn alternative movements from site to site. While changes in the traffic volumes on the mainline had an impact in specific instances, no definite trends were apparent. It was evident from these findings that proposed alternatives must be evaluated on a site-by-site basis, although, the following impacts were found for multilane divided, undivided, and two-lane roads:

- **Multilane divided:** The no restriction on left turns alternative performed better in terms of operation than the direct left turn restriction with U-turns at intersection or mid-block alternatives until the mainline volume threshold of 650 vehicles per lane per hour was reached. Beyond this volume threshold, U-turns at the intersection performed better than the no restriction and mid-block U-turn alternatives.
- **Multilane undivided:** Case 1, with no restrictions on left turns, and Case 3, mid-block U-turn, operationally performed almost equally, as long as the mainline volume per lane was less than 450 vehicles per hour per lane. Case 1 became the preferred alternative once the volume threshold of 450 vehicles per hour per lane was achieved.
- **Two-Lane roads:** The no restriction on left turns alternative and the left turn restriction with mid-block U-turn performed equally and both performed better than the U-turn at the next intersection alternative, for different mainline volumes.

When evaluating the operational effects of driveway and mainline volume changes, it was found that a change in driveway volume, ranging from 50 to 200 vehicles per hour, did not significantly



impact the network delay. However, changes in the mainline volume, ranging from 500 to 1200 vehicles per hour per lane, significantly increased the network delay. Therefore, mainline volume should be a factor in determining the use of a direct left turn alternative.

Based on the analysis, the jughandle design may be an alternative to be considered for multi-lane divided and undivided sites. When sufficient right-of-way is not available for a median U-turn, the jughandle may be an option, although, it would require right of way near the surrounding intersections in order to build the ramps. In addition, the jughandle is not in common use in Ohio, so it would require driver education and signage to implement such a design.

The concentrated left turn alternative has been shown to be an excellent solution for existing conditions as well as new development. For an existing site if there is the 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 through the use of right-in/right-out islands and signs. In the case of a new development, traffic circulation through the parking lot could be designed to allow vehicles to move to the signalized driveway and minimize any extra distance to be traveled. The signalized intersection timing would have to provide sufficient green time to the driveway so the delay would be minimal for the left turning vehicles. This option not only minimizes the delay for the exiting vehicles, but also for those entering the facility as well as for the through traffic on the mainline.

Since the operational analysis from the study sites was inconclusive on suggesting a particular U-turn treatment for a left turn restriction, further study of other influencing factors must be performed before parameters or standards can be developed. Assessing the surrounding signal capacities may provide some additional insight into the effects of restricting direct left turns. More specifically, when considering an alternative to the direct left turn, models should be run to evaluate the signal capacity of the signals surrounding the driveway before deciding upon an alternative.

Crash data was obtained for each sample site and analyzed to find the left turn crash rates at the driveway locations. The percentage of left turn crashes at many of the sites was high. These crashes could be prevented at these locations by restricting direct left turns. It was also demonstrated that conflict points are reduced when a restriction is placed on left turning traffic, in turn possibly reducing crashes. Finally, recent studies have found that a right turn followed by a U-turn movement is safer than the direct left turn.

Appropriate sites were not found to conduct a before and after safety study. One site, on US 20 in Perrysburg, is under construction to restrict direct left turns at driveway locations and encourage U-turn movements at signalized intersections. This is a potential site for studying the effects of restricting direct left turns from driveways and allowing U-turns at the intersection.



6. POLICY RECOMMENDATIONS

The study found the relative impacts of left-turn restrictions and left-turn restrictions with alternatives did not significantly vary where the through and left-turn movements in the approach of the left-turn deterred traffic had adequate capacity. Therefore, safety impacts should be the primary criteria in making decisions on an alternative.

There is variability from site to site in the impacts of restricting left-turns and the use of alternative treatments for accommodating the left-turn deterred traffic. Therefore, the alternatives proposed in this report should be evaluated on a site-by-site basis. Although traffic flow was improved in some cases, physical considerations may render these alternatives infeasible. It is recommended that ODOT adopt a geometric standard for accommodating transferred traffic.

The provision of geometric standards for these alternatives may be restricted to passenger cars and smaller trucks if right-of-way is not available for larger trucks. Larger vehicles may be accommodated through service roads or a different access point. A cross-access agreement, through township zoning and planning, would enable developments with restricted access to gain alternative access through access/service drives and streets.

Analysis shows that the transference of direct left-turn traffic should be considered based on mainline volume, volume/capacity ratio at the intersection and safety. Where there is a high incidence of driveway-related crashes, alternatives to left-turns should be considered. Mainline volume appears to be the most significant factor affecting the performance of the different cases tested in this study. Alternatives recommended in this report that accommodate left-turn deterred traffic are more applicable to and should be considered for multi-lane highways due to geometric requirements.

There is currently a lack of before-and-after crash data to evaluate the safety effectiveness of U-turns or jughandles. If the State of Ohio implements these recommendations, before-and-after crash data should be collected to evaluate the safety effectiveness of these alternatives.

In the case of multiple driveways between two intersections, restricting direct left turns from all but one signalized driveway appears to be a good operational strategy. This strategy requires a good internal traffic circulation patterns between the driveway access and the development.

Jughandles could prove effective with both multilane undivided and multi-lane divided highways. The jughandle design does not require a wide median, although several disadvantages exist. These disadvantages include: pedestrians crossing ramps as well as the main intersection; additional right-of-way necessary for the ramps; additional construction and maintenance costs for the ramps; and a lack of access to arterials for the areas adjacent to the ramps. Driver confusion could be lowered, however, if jughandles were used as the primary means of making turns along an arterial corridor.

If any of the recommended alternatives were adopted, standards for signing and signal operations should be established. Providing drivers with adequate information concerning these alternatives



through signing is an important element to positively impact safety and operations in the corridor.

Any alternative treatments for accommodating the left turn deterred traffic, such as mid-block U-turns or jughandles, may not be feasible with the existing rights-of-way at many sites. Wide medians are needed to store vehicles and provide a sufficient turning radius for larger vehicles. These alternatives may be superior to other choices but may be better applied in new development areas where plans can accommodate the required median widths. If alternatives are found to be effective, they may be considered for new developments where adequate right-of-way can be provided. There should be two sets of policies recommended to accommodate left-turn deterred traffic: one for existing roads and another for future developments.



7. INTEGRATION GUIDELINES

The following section provides guidelines for incorporating the findings of this research with the ODOT Access Management Manual, roadway design, and traffic engineering practices.

7.1 Access Management

The ODOT State Highway Access Management Manual requires a traffic impact study for new developments. If additional volume is generated from the alternative measures, the impacts of these could be estimated from traffic impact studies. The current ODOT State Highway Access Management Manual (Section 3.5) includes schematics for channelizing islands to provide right-in/right-out access for driveways for various American State Highway and Transportation Officials (AASHTO) Design Vehicles (ODOT 2001). It is recommended that a design be developed when the direct left-turn is restricted at the driveway. The channelizing islands provide the driver with guidance and ensure a right-in/right-out movement only. Signage would need to accompany the islands and would eliminate remaining driver confusion. A description of the sign requirements can be found in Section 7.3 as signs pertain to the Ohio Manual of Uniform Traffic Control Devices. These guidelines should be applied when left-turns are restricted through the use of a right-in/right-out movement, especially for undivided highways.

The alternatives described in this study provide indirect access to development and should be discussed in the Access Management Manual. These categories may be referred to as a special access category.

7.2 ODOT Design Practices

The following subsections include design elements that should be considered if any policies related to the transference of direct left-turn traffic is implemented.

7.2.1 Design Vehicles

If U-turn alternatives are adopted for a particular site, travel patterns of larger vehicles should be established in order to set the geometric standards. Based on the expected design vehicles for the mid-block U-turn or U-turn at an intersection, an appropriate turning radius must be selected and provided at the site of the U-turn. AASHTO's "Minimum Turning Paths for Design Vehicles" should be consulted to identify the required turning radius required (AASHTO 2001).

7.2.2 U-turn at Intersection

When designing for a U-turn movement at an intersection, many factors must be taken into consideration. The median U-turn crossover should be placed at least 600 to 700 ft before or after the signalized intersection. A U-turn movement should be made from a left turn lane (the innermost left turn lane when there are dual left turn bays). Vehicle turning radii from the AASHTO Manual must be applied to accompany the design vehicle of choice. The minimum width requirements for U-turns at an intersection are shown in Figure 23 as well. In addition,

any conflicting right-on-red movement from a side street must be eliminated to provide a safe maneuver for the vehicles making the U-turn movement.

TYPE OF MANEUVER		M. - MIN. WIDTH OF MEDIAN (ft) FOR DESIGN VEHICLE						
		P	WB-40	SU	BUS	WB-60	WB-80	TOT
		LENGTH OF DESIGN VEHICLE (ft)						
		19	50	30	40	65	85	110
INNER LANE TO INNER LANE		30	61	63	63	71	71	101
		18	48	61	51	60	60	89
INNER LANE TO SHOULDER		8	39	41	41	49	49	79

Figure 23. Minimum Width Design for U-turn (AASHTO 2001)

7.2.3 Mid-block U-turn

When designing mid-block U-turns, a left turn lane should be provided prior to the median opening to provide adequate storage and allow for deceleration of the vehicles making the U-turn. In addition, the median width required for the mid-block U-turn may vary by design vehicle and vehicle path. AASHTO provides guidance for minimum width designs, illustrated in Figure 23.

When there is no supporting access system for large vehicles, they must be accommodated in the U-turn area. This situation will probably occur only at or near truck facilities, major industrial areas, or truck staging areas. The movement can be accomplished in one of two ways. Both options are illustrated in Figure 24.



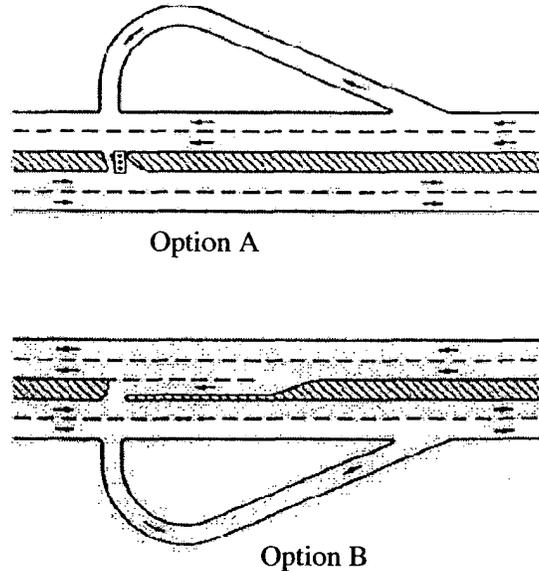


Figure 24: Options for Accommodating Large Vehicles or Narrow Medians (AASHTO 2001)

Option A in Figure 24 is similar to the jughandle described earlier in this report. Signalization is suggested at the median opening, which provides large vehicles enough time and space to turn. Option B allows large vehicles to pass through the mainline and follow a separate roadway where the vehicles can accelerate prior to merging with the through traffic (Florida Median Handbook 1997).

These options require a great deal more right-of-way and should only be used in exceptional cases where large vehicles have no other alternatives or when the median width is too narrow to permit a typical mid-block U-turn.

7.2.4 Jughandle

The main design concern for the jughandle alternative is the distance of the outlet from the signalized intersection. Typically, several hundred feet should be allowed to prevent blockage from queues from the signal on the cross street. As shown in Figure 25, the right turn from the jughandle can be YIELD-controlled, while the left turn should be STOP-controlled.

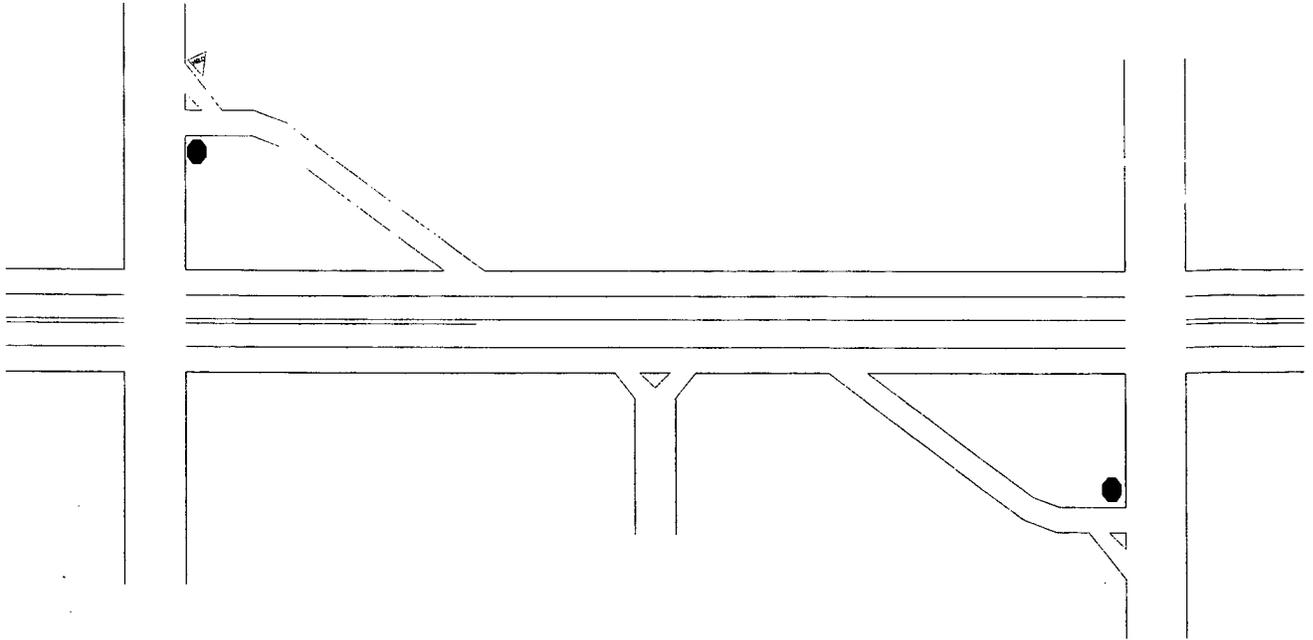


Figure 25: Jughandle Design

7.3 Traffic Engineering

Signage is important when implementing any new alternative to the direct left-turn. Figure 26 shows a signage plan for a mid-block U-turn. When a U-turn is implemented motorists must understand that U-turns are allowed at the designated crossovers.

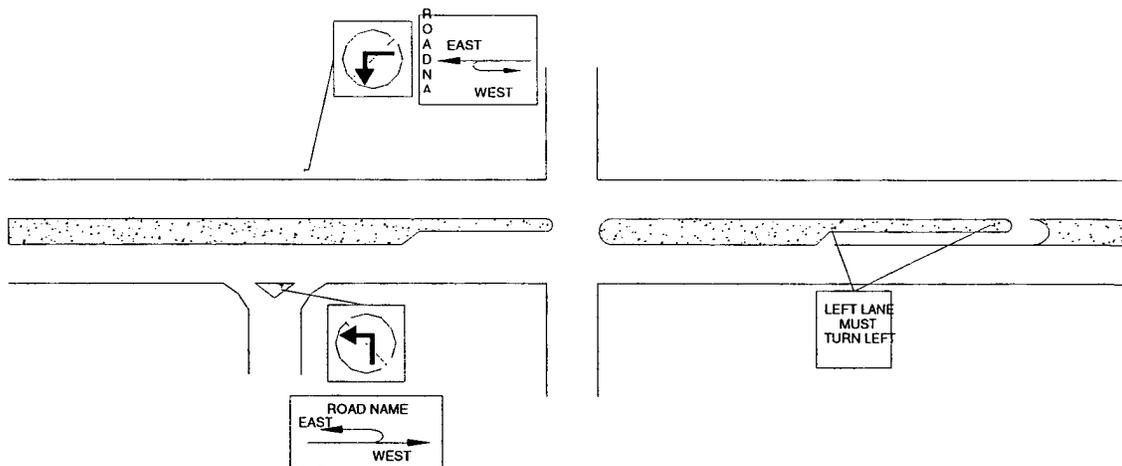


Figure 26: Example of Mid-block U-turn Signage Plan

A sign stating “No Left Turn” would need to be placed near the driveway exit: in addition, the sign must inform the motorist that a U-turn is available either at the next intersection or at the mid-block. Signs would have to be placed at the beginning and end of the U-turn storage lane to



inform motorists that they must turn if in that lane. The same lane and signage would be placed on the other side of the driveway for the vehicles wishing to make a left turn into the drive.

It is recommended that policies related to U-turns should be explored further and established. Drivers do not commonly use the current policy of "U-turn is permitted unless not restricted." "U-turn Permitted" signs should be placed wherever a U-turn is required to accommodate the left turn deterred traffic. At intersections where U-turns are permitted, left-turns and U-turns could be accommodated in the same lane. Left-turn pocket lane length should be based on left-turn volume and additional transferred left-turn deterred traffic.

In the case of the U-turn being encouraged at the nearest intersection, pavement markings on the left-turn and U-turn lanes must show the permitted movements. In addition, a sign would need to state that the U-turn is permitted during the green time of the left arrow on the signal. U-turns at signalized intersection should be a protected turn. While the protected left-turn phase is operational, the opposing right-turn should be restricted with a "No Right-Turn on Red" sign.



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