OPERATIONAL AND ECONOMIC ANALYSIS OF ACCESS MANAGEMENT

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16. Abstract The primary goal of this study was to analyze the operational and economic effects of access management strategies in South Carolina. This study investigated existing access management strategies practiced by different U.S. states through a review of literature, a nationwide survey, and a follow-up phone interview. Four access management strategies were analyzed for corridor-wide improvement: (1) driveway consolidation, (2) providing sufficient corner clearance distance from an intersection, (3) access restriction near signalized intersections, and (4) raised median implementation. In addition, one access management strategy (i.e., directional median opening) was analyzed for spot improvement. Each of the access management alternatives was evaluated in terms of travel time, number of stops, delay, and stopped delay using microscopic traffic simulation. Analyses conducted in this study indicated that the effectiveness of access management strategies were site-specific. However, the driveway consolidation strategy yielded a consistent improvement on almost all study corridors in terms of travel time. For the economic analysis, first, the perception of customers and businesses located along corridors with raised medians were surveyed. Then, the actual economic impact was examined and analyzed using a post-facto technique. Economic analyses indicated that the sales volume decrease of the affected businesses was similar to that of businesses in the control group. This finding suggests that the installed raised median was not the reason the affected businesses experienced a reduction in sales volume. The local and regional macroeconomics may have contributed to the decrease in sales volume of the affected businesses and their competitors. Based on this study's findings, provisions are suggested for the SCDOT Access and Roadside Management Strategies (ARMS) Manual.			
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EXECUTIVE SUMMARY

This study evaluated the operational impacts and economic effects of access management strategies for corridors in South Carolina (SC). Through a review of literature and a nationwide survey of different state Departments of Transportation (DOTs), this study examined the current access management practices in the U.S. A total of eleven corridors were selected for the operational analysis and seventeen were selected for economic analysis. Among these corridors, six were selected for joint operational and economic analyses. Findings from this study complement the previous safety-focused South Carolina Department of Transportation (SCDOT) sponsored study[1] by providing information regarding the operational impact of access management strategies on mainline and driveway traffic as well as on economic impact on businesses along the corridor.

<u>State DOTs Online Survey and Phone Interviews</u>

Thirty-two DOTs participated in the online survey, eighteen of which participated in the follow-up phone interview. The survey responses revealed that the most commonly implemented access management strategies include (i) limiting/separating access points, (ii) restricting driveways close to the intersection, (iii) installing raised medians, and (iv) modifying full driveway access to restricted driveway access. While most states examined the operational impact of access management, only seven states studied the economic impact of access management. However, the majority of the states that did not conduct economic studies indicated intent to consider economic impacts in their future access management standards.

<u>Operational Impact Assessment of Access Management</u>

In consultation with this project's Steering Committee, four traditional access management strategies were selected for testing corridor-wide improvement: (1) driveway consolidation, (2) providing sufficient corner clearance distance from an intersection, (3) access restriction near signalized intersections, and (4) raised median implementation. In addition, driveway improvement at a specific location along a corridor (referred to as spot improvement in this report) was evaluated. The access management scenarios were evaluated using microscopic traffic simulation. Travel time, number of stops, delay, and stopped delay were used to compare the traffic operations of mainline and driveway entering/exiting traffic. Although the analysis revealed that the operational impacts of access management strategies are site-specific, the driveway consolidation strategy yielded a

[1] W. A. Sarasua, J. H. Ogle, M. Chowdhury, N. Huynh, and W. J. Davis, "Support for the Development and Implementation of an Access Management Program Through Research and Analysis of Collision Data," Rep. No. FHWA-SC-15-02, South Carolina Dep. Transp., 2015

consistent improvement on almost all study corridors in terms of travel time reduction, and thus, is recommended for consideration for implementation.

Economic Impact Assessment of Access Management

Business perception of raised medians in South Carolina and the actual economic impact of raised medians on businesses were examined. A post-facto technique was used to analyze the three-year sales volume of businesses before and after raised median installations to assess the actual economic impact. Surveys were conducted to examine how businesses and their customers perceived the impact of raised medians. The factors associated with perception (i.e., related to businesses, customers, and corridors characteristics) were determined using the Chi-square test. The perception of the business community with regard to the impact of raised medians was determined using a binary logit model.

Findings from Operational and Economic Impact Assessments

Although access management strategies can restrict access to businesses, a properly designed access control can provide both safe and efficient roadways, as well as effective access to adjacent businesses. The purpose of the standards and guidelines provided by the SCDOT Access and Roadside Management Strategies (ARMS) manual is to ensure uniformity on roads to support safe and operationally efficient movements, while ensuring reasonable access to businesses. The key findings from this study are presented in the following, and they are recommended to be considered by the SCDOT for inclusion in future versions of the SCDOT ARMS and Highway Design manual.

Key Operational Impact Findings

- Non-traversable medians increased mainline travel time (up to about 18%) and mainline stopped delay (up to about 96%) compared to Two Way Left Turn Lanes.
- One alternative to fully closing driveways at the intersection influence area, allowing a right-in/right-out driveway can lead to decreased number of stops and delay for the mainline traffic when compared to fully closing access.
- Driveway consolidation decreased the mainline traffic travel time by as much as 5%.
- Providing corner clearance from an intersection following the SCDOT ARMS manual standards decreased travel time for the right-in[2] and left-in[3] driveway traffic up to about 53% and 56%, respectively, when compared to an intersection without corner clearance implementation.

[2] Right-in movements from the immediate upstream intersection (definition of upstream intersection is provided in *Figure 3-4*) to the driveway
[3] Left-in movements from the immediate upstream intersection to the driveway

- In general, among the four different what-if scenarios (i.e., non-traversable median, access restriction, providing corner clearance distance and driveway consolidation), access restriction (i.e., restricting left-turn movements within intersection influence area) reduced delay for right-in[4] driveway traffic in three corridors compared to existing conditions where driveways have full access.

Key Economic Impact Findings

- The majority of the businesses surveyed believe that raised medians had (or will have) an adverse effect on the average customer numbers per day, or sales per day. The following types of businesses indicated that impact of raised medians was (or will be) negative:
    - Small-sized businesses
    - Pass-by businesses
    - Businesses located along corridors with no raised median and recently installed raised median (i.e., median installed within the past year)
    - Businesses with their busiest times occurring during the peak hours
- Customers of the following businesses indicated that the impact of raised medians was (or will be) negative:
    - Pass-by businesses
    - Businesses located along corridors with a raised median installed within the past year
- Only 13% of customers prioritized accessibility as the most important factor in visiting a business.
- The findings of the post-facto analysis show that the sales volume decrease of the affected businesses was similar to that of businesses in the control group. This finding suggests that the installed raised median was not the reason the affected businesses experienced a reduction in sales volume. The local and regional macroeconomics may have contributed to the decrease in sales volume of the affected businesses and their competitors.

Based on the findings from this study and previous study[5], Table 1 presents a summary of the operational, safety and economic impacts of different access management alternatives.

[4] Right-in movements from the immediate upstream intersection to the driveway

[5] W. A. Sarasua, J. H. Ogle, M. Chowdhury, N. Huynh, and W. J. Davis, "Support for the Development and Implementation of an Access Management Program Through Research and Analysis of Collision Data," Rep. No. FHWA-SC-15-02, South Carolina Dep. Transp., 2015

Table 1: SC Access Management Project Impacts

	Operational	Safety	Economic
Non-Traversable Median	• Increased mainline travel time - all corridors up to 18% • Increased mainline stopped delay up to 96% • Increased left-in[6] and left-out[7] driveway travel time for all corridors	• Caused 0 crashes/ driveway for grass median • Caused 0.14 crashes/ driveways for raised median	Despite the three-year decrease in affected business sales volume, negative economic impact is insignificant as similar losses were observed in control group unaffected by median installation
Driveway Consolidation	• Reduced mainline travel time up to 4.5% • Decreased right-in[8] and left-in[6] driveway travel time	Reduced crash with increasing driveway spacing	
Corner Clearance	• Decreased the left-in[6] and right-in[8] driveway travel time • Increased the right-out[9] and left-out[7] driveway travel time in some cases	Increased crash frequency within the corner clearance distance with the increased AADT and number of driveways (within corner clearance)	
Right-In/Right-Out Only Driveway	• Increased right-in[8] driveway travel time for most corridors • Increased the left-in[6] driveway travel time for all corridors	Caused 0.16 crash/driveway for unchannelized right-in/right-out driveways compared to 0.36 crashes/driveway with full access driveways	

[6] Left-in movements from the immediate upstream intersection to the driveway

[7] Left-out movements from the driveway to the immediate downstream intersection (definition of downstream intersection is provided in *Figure 3-5*)

[8] Right-in movements from the immediate upstream intersection to the driveway

[9] Right-out movements from the driveway to the immediate downstream intersection

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LIST OF ABBREVIATION

ARMS	Access and Roadside Management Standards
RIRM	Recently Installed Raised Median
PIRM	Previously Installed Raised Median
NRM	No Raised Median
TWLTL	Two Way Left Turn Lane
RTUT	Right Turn U-turn
DLT	Direct Left Turn

CHAPTER 1 INTRODUCTION

1.1 Background

Access management, "the coordinated planning, regulation, and design of access between roadways and land development" [1], is used on urban arterials to mitigate the safety, operational, and economic problems. Access management strategies affect traffic safety and operations, as well as economic activity along highway corridors. Surrounding businesses on highway corridors can be affected by access management as they derive value from location, exposure and accessibility - the importance of which varies by business type. Oftentimes, business owners have a negative perception of access management and blame access modifications for business losses. However, research has shown that access management improvements can enhance both economic activity and traffic operations along a corridor [2]. This study focuses on the operational and economic analyses of access management strategies for urban arterials, which are "typically characterized by closely-spaced signalized intersections, high driveway density, and high traffic volumes" [3]. These characteristics result in a high rate of traffic incidents on urban arterials, over half of which are access-related [4]. However, the downsides of urban arterial traffic do not end with safety concerns. It can also result in congestion with higher travel times, and increased delays. The implementation of access management, however, can greatly improve operations and safety within the corridors in which they are implemented. Some successful techniques including providing sufficient signal and driveway spacing, sufficient corner clearance distance, auxiliary lanes, turning movement restrictions, and median treatment result in improved safety and added economic benefits [5]. The Transportation Research Board (TRB) Access Management Manual provides the following criteria regarding those access management practices that are most effective [1]:

1. *Driveway consolidation* provides sufficient distance between adjacent private driveways, between adjacent public roadways, or between a public roadway and a private driveway. The distance is measured, according to agency practice, from centerline to centerline or near edge to near edge of the access connections based on the direction of the traffic.

2. *Providing sufficient corner clearance distance* seeks to ensure sufficient distance from an intersection to the nearest access connection, specifically from the nearest edge of the pavement of the intersection to the nearest edge of the pavement of the access connection in the direction of the traffic.

3. *Access restriction* can be implemented in a multitude of ways. For the purpose of this study, it is defined as the use of channelization at the driveway intersection with the public road, to restrict left-turn movements into or out of the driveway.

4. *Non-traversable medians* are dividers that separate opposing traffic streams, designed to actively discourage or prevent vehicles from crossing the divider. A non-traversable median effectively restricts access at driveways to right-in/right-out except at those driveways served by median openings.

The safety benefits of the access management strategies defined above are widely documented and accepted with little to no contention. For example, multiple statewide studies have indicated that crash rates tend to increase as access density increases [1]. Roadways with non-traversable medians also have lower crash rates than the corridors with Two Way Left Turn Lanes (TWLTL) and those that are undivided [1]. The results from a number of studies on the operational impacts of Direct Left Turn (DLT) alternatives determined that the effects vary with changing traffic. According to Chowdhury et al. (2005), depending on the arterial volume range, DLT movements result in reduced average network delay, when compared with Right Turn followed by U-turn (RTUT) movements [5]. It was also determined that as volumes of through traffic increase, left turns from driveways caused substantially less delay from RTUT movements than from DLT movements [6]. Further, the restriction of right-in/right-out access over a range of arterial traffic volumes was effective in ensuring continuous traffic flow [7]. There is slightly more ambiguity, however, concerning economic impacts, which has led to a growing interest in the quantification of these impacts in order to provide a more holistic justification for the implementation of various access management measures.

While previous studies have focused on different operational elements of access management strategies, those impacts are corridor-specific to the respective studies. An analysis of specific corridors with different geometric and land use/business characteristics in South Carolina (SC) needed to be conducted to assess both the operational improvements and deteriorations for various access management strategies. Moreover, the type of access control used affects the accessibility to businesses along corridors. Therefore, a thorough analysis of economic impacts was necessary because not all businesses have the same level of sensitivity to different access management strategies. Consequently, the perceived and actual effect of those economic impacts were comprehensively quantified and analyzed in this research to understand how access modifications affect businesses.

1.2 Significance of the Work

Access management strategies affect not only roadway safety and operational performance, but also the access to surrounding businesses. The impacts of access modification on both traffic operations and roadside businesses' economic conditions are discussed in Chapter 2 and APPENDIX A. Following the literature review, it was necessary to conduct a state-specific access management study on operational and economic impacts in SC. The purpose of this evaluation of the operational and economic impacts of access management strategies is to develop access management recommendations by integrating the findings of this study with the existing policy. This research quantified the impacts of four access management techniques: driveway consolidation, provision of sufficient corner clearance distance from an intersection, access restriction, and non-traversable medians, allowing for a comparison of the effectiveness of each, in a case-by-case basis. Another common practice for many Departments of Transportation (DOTs) entails the implementation of driveway-specific access modifications, also known as spot improvement. This spot improvement study helped to quantify the operational and economic benefits for driveway-specific modifications. Responses collected from the online survey and telephone interviews can also facilitate the creation of new guidelines for statewide access management policies and standards. This research addressed the lack of state-level economic impact studies by examining the actual economic impact on businesses, and investigating how businesses and customers perceive the impact of raised medians and different spot improvements in South Carolina.

1.3 Research Objectives

The objectives of this study are the following:

1. To quantify operational impacts of different access management strategies along selected corridors in SC;
2. To quantify economic impacts of different access management strategies along selected corridors in SC;
3. To compare operational and economic benefits of different access management strategies along selected corridors in SC; and
4. To develop policy recommendations and recommend potential changes to the next editions of the SCDOT Access and Roadside Management Strategies (ARMS) and Highway Design Manual to improve access management strategies.

1.4 Report Organization

This report has six chapters. Chapter 2 reviews national and state guidelines and existing research as it relates to the operational and economic impacts and design of the access management strategies in question. The complete literature review can be found in APPENDIX A. The state agencies' responses to online surveys and telephone interviews are also summarized in Chapter 2, and detailed in APPENDIX B. Chapter 3 outlines the research method for the operational impact study including the steps associated with the corridor selection, data collection, model development for simulation analysis, and development of what-if scenarios of access management strategies. Chapter 3 also provides the research methods for economic analysis which includes surveys, Chi-Square tests, post-facto technique and binary logit model. The operational impact of access management strategies is discussed in Chapter 4. The results from the economic and safety analysis are summarized in Chapter 5. Chapter 6 concludes the report with a discussion of summary findings and recommendations for potential additions to the SCDOT ARMS manual and Highway Design Manual.

CHAPTER 2 SUMMARY OF ANALYSIS OF BEST PRACTICES

2.1 Summary of Previous Research Review

In order to examine current state access management practices in the United States, the research team reviewed earlier studies. The literature review examined national guidelines and resources covering operational and economic impacts of access management, state agency manuals covering warrants and design guidelines, and methods and measures of effectiveness for operational impacts and design recommendations. The full contents of the literature review, as it relates to operational and economic impacts of raised medians (and thus indirect left-turn movements–U-turns), driveway consolidation, access restriction within the corner clearance distance in the intersection's influence area and left-turn-in-and–out restrictions, can be found in APPENDIX A. In general, past research has found that at signalized intersections, U-turns do not adversely impact operations, and that RTUT movements as alternatives to DLT movements can have better operational performance under certain traffic conditions.

Other studies did measure operational impacts through varying measures of effectiveness (MOEs). Some studies analyzed delay to turning vehicles at driveways, while others investigated traffic operations along the mainline by analyzing delay, travel time, and average speed for these movements. Several studies came to a similar conclusion that changes in mainline volume were more impactful to mainline traffic operations than other factors (i.e., access density). A number of studies also noted that there are volume thresholds (driveway and mainline) at which certain access management techniques (RTUT instead of DLT, restricting left-in, restricting left-out) become operationally advantageous. Additionally, past research has noted that increased access density has negative effects on both through-traffic and driveway traffic, and thus have presented alternative methods of establishing guidelines for access spacing and corner clearance distance according to these findings. Finally, there is a relatively established history of using microsimulation to evaluate operational impacts of access management strategies; many of which use VISSIM and Synchro.

The economic impacts of access management appear to sometimes be positive and sometimes negative. Studies performed in Iowa, Minnesota, and Utah found that access management has positive effects on the surrounding businesses. Studies in Arkansas and North Carolina found access management to have no impact on businesses (i.e., neither positive nor negative). The Texas and NCHRP 231 studies found that gas stations, non-durable goods retailers, and service businesses to be negatively affected by access management treatments. These findings suggest that the economic impact of access management is site-specific, and thus, no study's finding can be uniformly applied to all situations.

2.2 Online Survey and Phone Interview Results from State Transportation Agencies

In order to get in-depth insights about the state transportation agencies' access management practices, an online survey was prepared and circulated among the U.S. State Departments of Transportation. The survey was comprised of seven general questions regarding all corridor-wise access management strategies, and nineteen questions specific to different alternatives. These questions mainly identified the factors affecting access modification and challenges related to access management project implementations. Both open-ended, and multiple-choice questions were included. The online survey questions can be found in APPENDIX B. In total, 32 states participated in the online survey. Among them 25 DOTs submitted full responses, and seven DOTs submitted partial responses. Figure 2-1 shows the states participated in the online survey. Discussion about the responses for each survey question from the states is included in APPENDIX B.

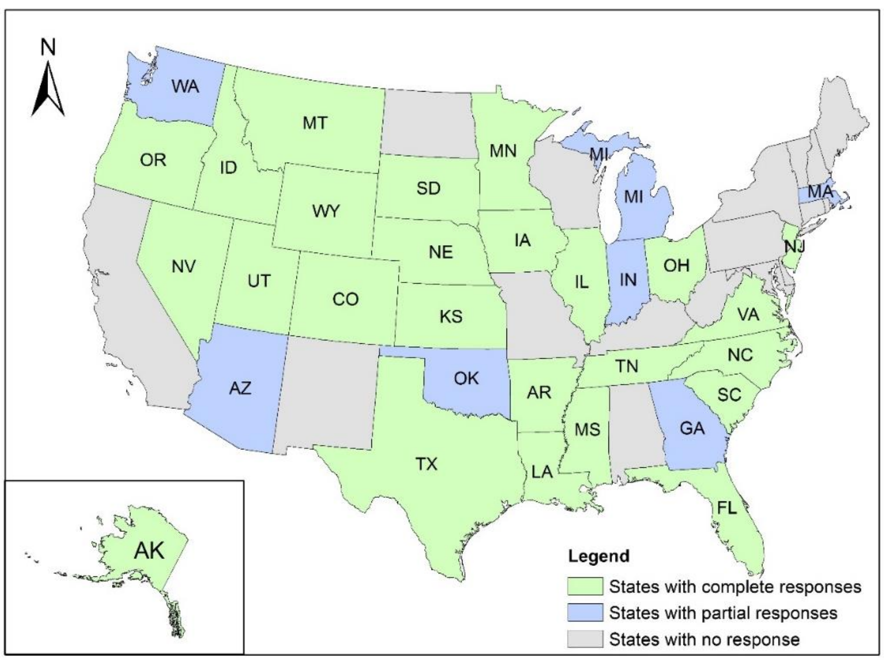

Figure 2-1: Online Survey Participants for Access Management Study

After the online survey responses were analyzed, further questions were posed through telephone interviews about retrofitting corridors, procedures for driveway closures, usage of frontage road/spot improvements, and dealing with business owner resistance. As shown in Figure

2-2, eighteen states completed the interview. Most of the questions were open-ended in the telephone interview, and some of them were multiple-choice questions. The telephone interview questions and answers are attached in APPENDIX B. A summary of the responses from the online survey and phone interview are presented in [8].

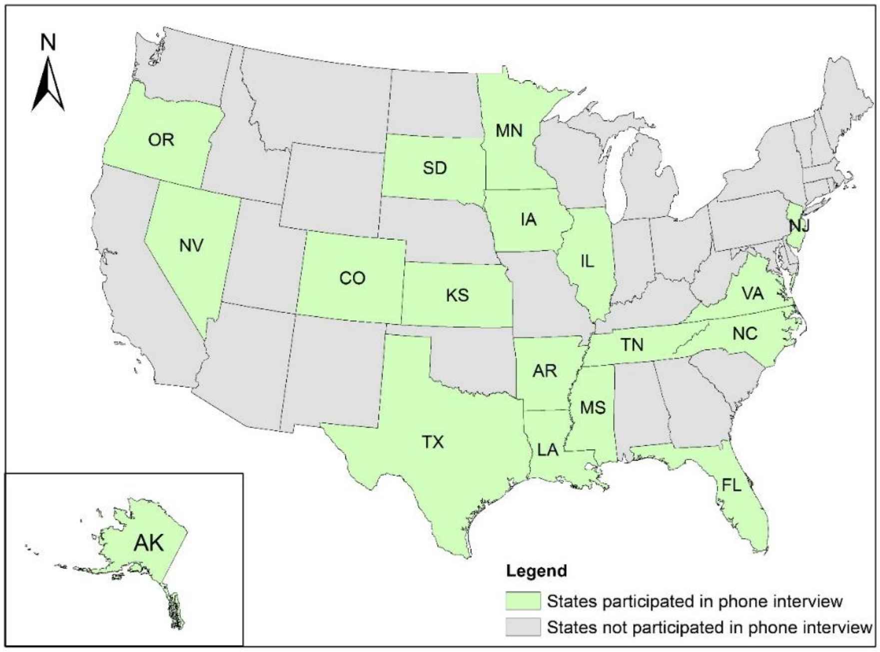

Figure 2-2: Phone Interview Participants for Access Management Study

2.3 Summary

In summary, a review of national guidelines and state access management related manuals was conducted, and this review can be found in APPENDIX A. This review provides various warrants, recommendations, and guidelines, currently adopted by state transportation agencies, related to the access management strategies studied in this project. Numerous studies conducted regarding the impact of access management resulted in varying recommendations on topics, such as spacing criteria for access points. The review includes operational and economic impact of access management. An online survey was conducted followed by telephone interviews with different DOTs. In general, most DOTs lack the funding to conduct impact studies of access management strategies in terms of operational and economic effects. However, most state DOTs indicated that conducting an access management impact study would be valuable. The most commonly identified barrier to implementing these access management strategies is the opposition from local businesses. The complete findings from the survey and interviews can be found in APPENDIX B.

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CHAPTER 3 RESEARCH METHOD

3.1 Corridor Selection

3.1.1 Corridors for Operational Impact Analysis

Five corridors were selected for analysis – three 5-lane corridors (two lanes each direction with a TWLTL) and two 7-lane corridors (three lanes each direction with a TWLTL), in order to compare the operational functionality of different access management strategies. The selection of the corridors was based on a recently completed SCDOT study [9] which investigated access-related incidents along U.S. and S.C. routes in South Carolina. [9] determined eleven priority routes based on studies of the driveway related crash frequency per year. These eleven routes were scanned for roadway segments (of two-lanes and three-lanes in each direction) with existing TWLTLs, high AADT [10] (greater than 20,000 vph), high commercial land use, and high driveway densities. From the eleven routes, five corridors were selected for operational impact assessments in this report, all of which have high driveway density (density greater than 35 driveways/mile). Among the five-lane segments identified, a 1.5 mile stretch on S.C. 146 (Woodruff Road) in Greenville County was chosen. This segment is on the corridor with the highest crash rate (0.7 crashes per driveway per year) and is known to SCDOT for excessive and recurrent peak hour congestion. The other two corridors are located in Richland County, U.S. 1 Richland (Two Notch Road) and U.S. 176 Richland (Broad River Road). Of the seven-lane segments identified, the two selected corridors are on HWY U.S. 29 (Wade Hampton Blvd 1 and Wade Hampton Blvd 2), which has a crash rate of 0.22 crashes per driveway per year. Detailed information for these five corridors is shown in *Table 3-1*. These selected corridors are also shown in Appendix C.

Table 3-1: Corridors for Operational Analysis

Corridor Segment	Length (miles)	AADT (veh/day)	Posted Speed (mph)	Median Treatment	Signals/ Mile	Driveways/ Mile
S.C. 146 Greenville	1.41	34,600	45	TWLTL	4.3	44.7
U.S. 176 Richland	1	36,500	40	TWLTL	6	72
U.S. 1 Richland #1	1.32	21,600	40	TWLTL	3.8	63.6
U.S. 29 Greenville #1	1	33,700	45	TWLTL	5	68
U.S. 29 Greenville #2	1.59	26,600	45	TWLTL	3.8	34.6

3.1.2 Corridors for Economic Impact Analysis

A total of seventeen corridors are included in this study for economic impact analysis as advised by the SCDOT steering committee members. Figure 3-1 shows their approximate locations in the state of SC. The road names and cities where these corridors are located, as well as the types of survey and analysis performed for each corridor is presented in Table 3-2. Table 3-2 also provides information regarding the access management projects in Corridors 9 through 17.

The selected corridors are classified as one of three types according to the following criteria:

- RIRM (recently installed raised median) - corridors with raised medians installed within the past year.
- PIRM (previously installed raised median) - corridors with raised medians installed more than two years ago.
- NRM (no raised median) - corridors without a raised median.

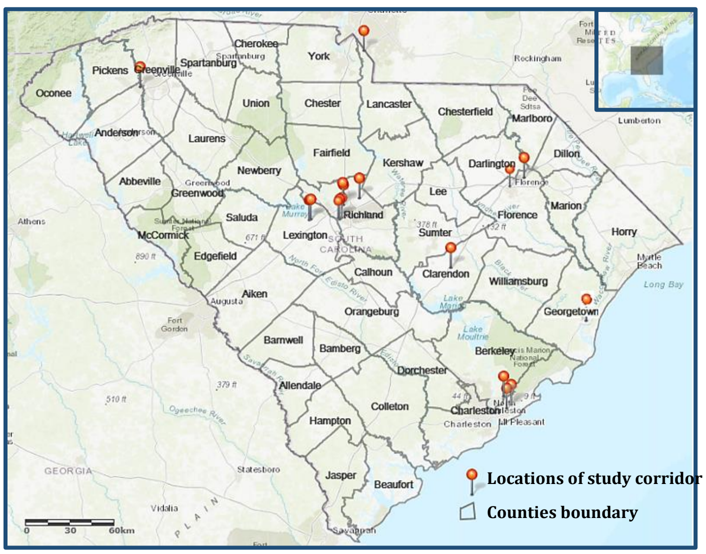

Figure 3-1: Locations of Study Corridors

As shown in Table 3-2, there are five NRM corridors, ten PIRM corridors, and two RIRM corridors in this study. Among the PIRM corridors, corridors nine through fourteen and corridor seventeen had raised medians installed between 2006 and 2015 and were used for the post-facto analysis. The information about businesses is obtained from the ReferenceUSA database. At the time of this study, ReferenceUSA contained sales volume data from 2003 to 2016. Since the sales volume data was unavailable after 2016, the post-facto analysis could not be performed on the RIRM corridors. Customers of businesses located on the NRM corridors were not surveyed since these businesses and their customers are not impacted by raised medians.

Table 3-2: Study locations for Economic Impact Assessment

Corridor	Road name	City	Type of median installation	Analysis Method					Access management Project in last ten years		
				Survey		*Chi-square test*	*Post-facto analysis*	*Binary logit model*	*Location*	*Type of project*	*Completion date*
				B[1]	*C*[2]						
1	Devine ST	Columbia	NRM	✓	-	✓	-	✓	NA	NA	NA
2	Assembly ST	Columbia	NRM	✓	-	✓	-	✓	NA	NA	NA
3	U.S. 378 Lexington #1	Lexington	NRM	✓	-	✓	-	✓	NA	NA	NA
4	U.S. 378 Lexington #2	Lexington	NRM	✓	-	✓	-	✓	NA	NA	NA
5	US 76	Florence	NRM	✓	-	✓	-	✓	NA	NA	NA
6	Gervais	Columbia	PIRM	-	✓	✓	-	-	NA	NA	NA
7	Harden ST	Columbia	PIRM	✓	✓	✓	-	✓	NA	NA	NA
8	Rosewood ST	Columbia	PIRM	✓	✓	✓	-	✓	NA	NA	NA
9	Two Notch Rd (U.S. 1 Richland #2)	Columbia	PIRM	✓	✓	✓	✓	✓	From Sparkleberry Ln to Rivekin Rd.	Added one raised median	2011
10	U.S. 17- Phase 1	Mt Pleasant	PIRM	✓	-	✓	✓	✓	From I-526/Hungry Neck to Isle of Palms Connector	- Added raised medians - Added one lane in each direction	2006
11	U.S. 17- Phase 2	Mt Pleasant	PIRM	✓	-	✓	✓	✓	From Isle of Palms Connector to SC 41	- Added raised medians - Added one lane in each direction	2013
12	U.S. 17- Phase 3	Mt Pleasant	PIRM	✓	-	✓	✓	✓	From SC 41 to Darrel Creek	- Added raised medians - Added one lane in each direction	2013
13	S.C. 327	Florence	PIRM	-	-	-	✓	-	SC327 at I-95	- Added one raised median - Removed one driveway - Added one new access road - Converted a full access driveway to right-in/right-out	2013
14	S.C. 160	Fort Mill	PIRM	-	-	-	✓	-	S.C. 160 at U.S. 521	- Added one raised median	2008
15	S.C. 261	Manning	RIRM	✓	✓	✓	-	✓	S.C. 261 at Edgewood Dr.	- Added a raised with two mid-block directional left turns	2016
16	S.C. 153	Powdersville	RIRM	✓	✓	✓	-	✓	S.C. 153 at Anderson Rd.	Restricted left turn	2016
17	Ocean Hwy	Pawleys Island	PIRM	-	-	-	✓	-	From Waverly Road to Baskerville Drive	- Added raised medians	2015

[1]***B***: Businesses [2]***C***: Customers

3.1.3 Corridors for both Operational and Economic Impact Analysis

A total of seventeen corridors from South Carolina were selected to evaluate the economic impact of access management strategies to accomplish both research Objective 2 and Objective 3 as stated in Section 1.3 of this report. In order to investigate the combined effect of access management on both operations and economy, five corridors were selected. An additional corridor from Powdersville, SC, was selected where a directional median opening was installed in front of a driveway, in order to evaluate the operational impact of the spot improvement projects implemented by SCDOT, as shown in *Figure 3-2*. *Table 3-3* presents the details of these six corridors. An aerial view of the selected corridors for both operational and economic analysis can be found in Appendix C.

Figure 3-2: Directional median opening in the Powdersville corridor

Table 3-3: Corridors for Economic and Operational Analysis

Corridor Segment	Length (miles)	No. of lanes in one direction	AADT (veh/day)	Posted Speed (mph)	Median Treatment	Signals/ Mile	Driveways/ Mile
U.S. 17 Charleston	1.1	3	37,700	45	Raised Median	2.7	29.1
U.S. 1 Richland #2	1	2	30,800	45	TWLTL and Raised Median	4	21
U.S. 378 Lexington #1	1	2	31,000	35	TWLTL	5	35
U.S. 378 Lexington #2	1.18	2 and 3	32,500	35	TWLTL and median	4.2	48.3
U.S. 76 Florence	1	2	17,000	35	TWLTL and median	7	79
S.C. 153 Powdersville	1.14	2	32,600	55	Median	2.6	16.7

3.2 Simulation Model Development for Operational Impact Assessment

3.2.1 Data Collection

In addition to the descriptive data shown in Table 3-1 to Table 3-3, signal plan, timing, turning count data, driveway volume data, and mainline travel times were needed to calibrate the base model. The data collection steps are described in the following pages.

Table 3-4: Signalized Intersection Turning Volumes for Corridors Selected for Operational Analysis (Field Data)

Corridor	Data collection time	Intersection	Southbound			Westbound			Northbound			Eastbound			Total
			Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	
S.C. 146 Greenville	5:00 pm to 6:00 pm	Merovan	99	13	143	0	1435	25	241	22	0	188	1776	0	3942
		Smith Hines	5	1	12	63	1278	0	186	2	149	24	1717	49	3486
		Walmart	84	13	104	20	1738	34	239	23	3	67	1287	121	3733
		Feaster	149	164	79	93	1133	47	239	279	149	193	1435	46	4006
		East Butler	48	78	25	300	1091	25	139	39	357	18	1428	233	3781
		Rocky Creek	10	1	48	26	1311	13	82	2	35	49	1932	64	3573
U.S. 176 Richland	4:30 pm to 5:30 pm	I-20 W Ramp	300	6	792	116	1172	0	0	0	0	0	1150	112	3648
		Marley Drive	131	19	71	41	1886	41	116	4	34	34	1106	53	3536
		Young Drive	60	14	12	74	1622	22	46	20	72	12	1104	22	3080
		Rushmore Road	82	0	84	0	1726	84	0	0	0	38	1020	0	3034
		St Andrews Prkwy	48	0	66	32	1744	76	0	0	0	48	1120	2	3136
		St Andrews	88	64	12	80	1210	22	230	46	312	8	894	268	3234
U.S. 1 Richland #1	4:30 pm to 5:30 pm	Risley Road	44	30	48	36	696	30	21	24	43	49	1080	41	2142
		Columbia Mall	124	2	64	28	743	112	8	2	19	60	1036	14	2212
		Faust Street	46	1	26	9	989	79	6	1	14	21	1360	4	2556
		Parklane Road	53	560	171	223	571	39	452	461	71	198	577	448	3824
		Big K Mart Dvwy	12	0	8	1	683	19	0	0	2	11	828	0	1564
U.S. 29 Greenville #1	4:45 pm to 5:45 pm	W Lee/Cherokee	220	53	3	92	1401	182	45	77	77	11	1891	30	4082
		S-23-166	47	48	29	58	1191	31	326	30	24	60	1562	474	3880
		Vance	2	2	8	13	1302	0	11	0	24	4	1685	6	3057
		Tappan	183	16	61	10	1175	126	35	25	16	54	1518	55	3274
		S Watson	32	43	41	30	1206	2	70	71	41	31	1573	67	3207
U.S. 29 Greenville #2	4:30 pm to 5:30 pm	Old Rutherford	22	43	90	3	1739	33	1	54	1	228	1762	57	4033
		Bella Michele	165	21	91	11	1697	163	51	17	13	43	1631	13	3916
		S Suber	238	195	173	15	1726	146	60	102	18	174	1546	74	4467
		Dill Creek	55	33	34	87	1617	35	112	25	77	56	1488	68	3687
		Dil Avenue	42	2	16	45	1680	40	30	4	42	25	1707	71	3704
		S Buncombe	346	339	172	338	1343	169	474	504	160	257	1257	214	5573

Table 3-5: Signalized Intersection Turning Volumes for Corridors Selected for both Operational and Economic Analysis (Field Data)

Corridor	Data collection time	Intersection	Southbound			Westbound			Northbound			Eastbound			Total
			Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	
U.S. 17 Charleston	4:30 pm to 5:30 pm	Hungry Neck	372	0	29	177	2113	255	586	0	182	40	1436	336	5526
		Venning Road	343	202	65	58	1463	242	64	115	55	93	2151	103	4954
		James Nelson	28	9	39	71	1461	23	185	7	61	66	2232	135	4317
		Montclair	124	1581	3	155	10	97	47	2322	89	13	2	9	4452
U.S. 1 Richland #2	5:15 pm to 6:15 pm	N. Brickyard	290	6	342	9	1320	274	45	39	19	309	1319	29	4001
		Rivekin Road	350	1301	0	396	0	97	0	1509	92	0	0	0	3745
		Sparkleberry	200	900	56	457	202	93	177	1254	343	183	157	93	4115
		Valhalla Drive	27	10	36	189	1119	7	156	3	272	24	1425	96	3364
U.S. 378 Lexington #1	4:45 pm to 5:45 pm	N Lake Drive	86	0	612	0	1456	104	0	0	0	500	1192	0	3950
		Coventry Drv	34	12	77	20	1423	52	69	7	19	71	1090	43	2917
		Walmart	75	6	232	11	1239	71	37	11	7	160	969	17	2835
		Mallard Lakes	55	44	25	40	1181	432	363	52	39	69	683	83	3066
		Scotland Drv	39	7	78	17	1384	40	30	3	20	24	952	36	2630
U.S. 378 Lexington #2	5:00 pm to 6:00 pm	Barr Road	0	0	0	368	975	0	186	0	327	0	677	97	2630
		Gibson Road	264	78	12	45	1202	566	210	306	57	11	1114	93	3958
		Medical Cntr	124	3	124	9	1561	53	23	17	23	37	1137	5	3117
		Park Road	186	7	103	24	1696	200	66	25	44	87	1249	21	3708
		Old Chapin	78	173	127	77	1345	78	461	206	29	151	972	416	4113
U.S. 76 Florence	4:30 pm to 5:30 pm	State S-21-186	0	0	0	16	887	0	41	0	13	0	595	25	1577
		Warley Street	50	30	50	12	889	33	19	13	16	22	570	21	1725
		S Mcqueen	77	30	39	5	779	31	18	20	5	13	603	23	1643
		S Coit Street	85	157	45	28	778	46	46	131	18	21	680	25	2060
		S Irby Street	57	510	66	144	641	46	122	452	106	55	539	155	2893
		S. Dargan	27	131	57	99	733	16	32	62	145	37	654	53	2046
		S Church	215	889	69	0	715	142	113	603	63	0	698	134	3641
S.C. 153 Powdersville	4:30 pm to 5:30 pm	Hood Road	179	85	36	220	1252	155	31	61	101	42	977	14	3153
		Anderson Rd	136	765	64	75	178	130	92	712	70	193	211	35	2661
		River Road	45	157	85	46	46	778	680	21	18	0	0	2060	3936

- First, historic intersection traffic counts were obtained from SCDOT. Second, typical traffic movements were studied from the Google map, which shows the status (i.e., traffic speed) for any typical traffic movement in a given time period within a week. Based on these two different sources, the PM peak hours were selected for data collection for all simulated corridors. Table 3-4 presents the peak hour turning volume count for the corridors selected for operational analysis, and Table 3-5 shows the peak hour count for the corridors selected for both operational and economic analysis. For each intersection, traffic counts were collected in mid-week.
- Second, SCDOT provided the signal timing plans, which were used to model phase splits, cycle length, and signal coordination.
- Third, driveway entering and exiting volumes were estimated and assigned using field counts and trip rates from the ITE Trip Generation Manual [11].

Table 3-6: Field Travel Time for Simulated Corridors

Corridor	Length (miles)	Approach	Avg. Travel Time (s)	Standard Deviation of Avg. Travel Time(s)
S.C. 146 Greenville	1.41	Eastbound	307	43.1
		Westbound	268	28.8
U.S. 176 Richland	1	Northbound	147	5.7
		Southbound	122.5	6.4
U.S. 1 Richland #1	1.32	Eastbound	192.5	17.1
		Westbound	186.7	12.5
U.S. 29 Greenville #1	1	Eastbound	118	26
		Westbound	128	18
U.S. 29 Greenville #2	1.59	Eastbound	195.5	52.5
		Westbound	148.5	34.7
U.S. 17 Charleston	1.1	Eastbound	119.6	52.2
		Westbound	122.8	29.5
U.S. 1 Richland #2	1	Eastbound	187.5	19.7
		Westbound	224.5	12.5
U.S. 378 Lexington #1	1	Eastbound	136	20
		Westbound	142	10
U.S. 378 Lexington #2	1.18	Eastbound	179	39.41
		Westbound	160.6	40.1
U.S. 76 Florence	1	Eastbound	137.1	13.1
		Westbound	234.7	36.3
S.C. 153 Powdersville	1.14	Eastbound	111.5	2.5
		Westbound	116.4	12.8

- Fourth, the floating car method was used during the peak period to capture corridor travel times for both directions (i.e., Eastbound/Northbound, Westbound/Southbound).

The travel time results from the floating car method are shown in Table 3-6. The ITE Trip Generation Manual provided information on how many trips to expect (both entering and exiting based on land-use) but not from which direction they would come or leave. These ratios were determined using engineering judgement, as well as a matrix that ensures that the entering and exiting volumes at the signals at the East/North and West/South end of the sections were consistent with the volume counts conducted in the field.

3.2.2. Base Model Calibration

After developing the base geometry, and signal controllers, and inserting gateway and driveway volumes, calibration was done for each model to match the travel times (i.e., Eastbound/Northbound, Westbound/Southbound travel time) collected in the field. Calibration was complete when the base models "produced average travel times during the peak hour within 10% of the travel times measured in the field" [12]. To calibrate the models, principles from Park and Schneeberger's discussion of "microscopic simulation model calibration and validation" were used for corridors with posted speed limit 45 mph [13]. The study identified "emergency stopping distance, lane-change distance, desired speed distribution, number of observed preceding vehicles, average standstill distance, waiting time before diffusion, and minimum headway as controllable parameters which may be reasonably adjusted to calibrate the model." Some of these parameters were adjusted within the tolerable ranges suggested by Park and Schneeberger's study in order to calibrate the model. The finalized values of these parameters for each corridor are shown in Table 3-7 below. For all simulated corridors, only the peak hour was tested (4,500 sec. run time including 900 sec. warm up).

In order to calibrate all corridors, the desired speed distributions were adjusted to closely match the travel times from simulated corridors with the real-world travel times for mainline traffic. In Appendix C, the desired speed decisions for the corridors are shown in Figure C-12 and Figure C-13.

Table 3-7: Calibration Parameters Used in Base Model Calibration (posted speed 45 mph)

Parameter	Acceptable Range	Selected Value					
		S.C. 146 Greenville	U.S. 29 Greenville #1	U.S. 29 Greenville #2	U.S. 17 Charleston	U.S. 1 Richland #2	S.C. 153 Powdersville
Desired Speed Distribution (mph)	35 to 55	35 to 47.0	42.3 to 48.5	40 to 55	40 to 55	35 to 47	40 to 55
Number of Observed Preceding Vehicles	1 to 4	3	4	4	4	4	4
Average Standstill Distance (ft.)	3.28 to 9.84	7.51	6.56	6.56	6.56	7.55	6.56
Waiting Time Before Diffusion (s)	20 to 60	20	60	60	60	20	60
Minimum Headway (ft.)	1.64 to 23	6.99	1.64	1.64	1.64	2.99	1.64

An additional important calibration parameter is acceptable gap time for median and driveway turning movements. Two sources for acceptable minimum gap times were found in the literature [14] [15], one addressing left and right turns and the other addressing U-turns.

Table *3-8* shows the suggested gap times for each of these sources. These values were adopted for use in the base models for all corridors.

Table 3-8: Minimum Gap Acceptance Times for Turning Movements

Turning Movement	Minimum Suggested Gap Acceptance Time (s)	
	Liu et al. [15]	**Siddiqui** [14]
U-turns	6.3 (2-lanes) | 5.1 (3-lanes)	N/A
Left-turns in	N/A	3.6
Left-turns out	N/A	3.1
Right-turns	N/A	3.0

Another important factor is turning speed of right-turners, as this has the potential to impact following right-lane mainline traffic and thus mainline travel times. The literature review of typical right turn speeds revealed a range between 10 and 18 mph [16] [17], which is used in this study. This speed was also used as the speed for TWLTL traffic. An example of the TWLTL modeling approach is shown below in Figure 3-3.

Using a different random seed in each run, the simulation model was run ten times as a first step in estimating the required number of simulation run. The average travel time results for the simulated corridors are shown in Table 3-9. The average of the travel times did not exceed a 10% variance with respect to the field collected data and thus, the calibration of the models was considered complete. The calibrated models are then incorporated with the optimized traffic signal time.

The ACS-Lite adaptive signal controller module was used for two corridors, U.S. 17 Charleston and U.S. 378 Lexington #1. Although different adaptive signal control methods were implemented in the field, the ACS-Lite system was the only available adaptive signal control method to be implemented with the VISSIM traffic simulation software at the time of this study. The base models were calibrated against the field captured travel times.

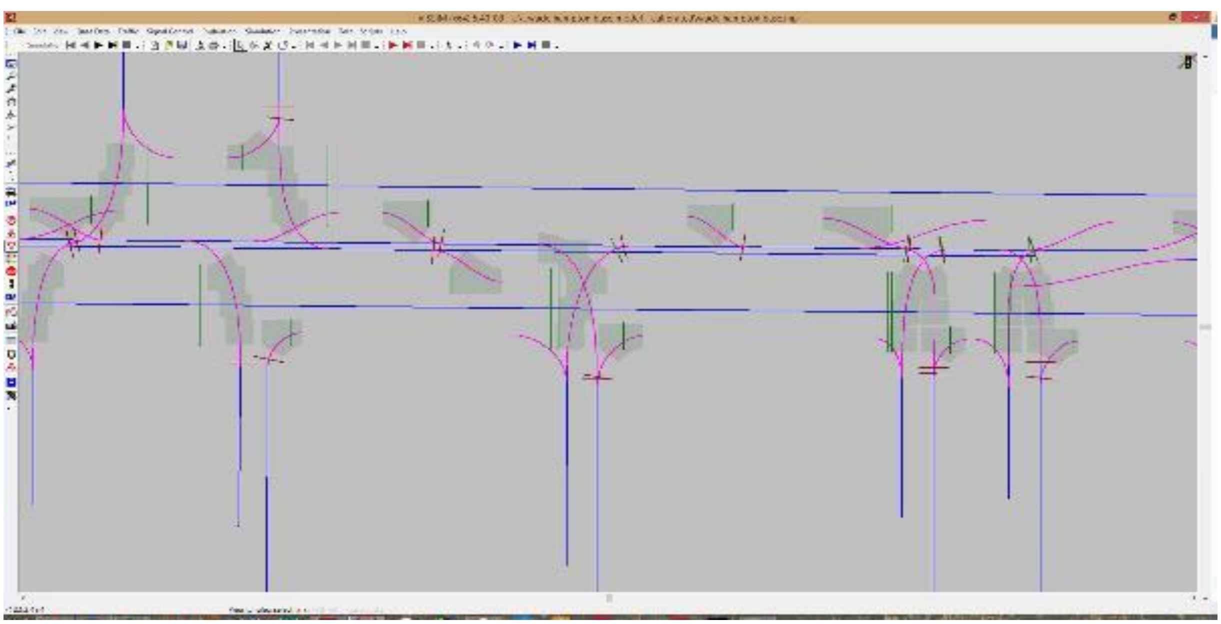

Figure 3-3: TWLTL Modeling using Priority Rules and Conflict Areas

Table 3-9: Simulation Travel Time Calibration

Corridor	Approach	Avg. travel time from field (s)	VISSIM Avg. travel time (s)	Difference (%)
S.C. 146 Greenville	Eastbound	307	295	4
	Westbound	268	259	3.5
U.S. 176 Richland	Northbound	147	136	7.5
	Southbound	122.5	114	6.9
U.S. 1 Richland #1	Eastbound	192.5	175	8.8
	Westbound	186.7	168	10
U.S. 29 Greenville #1	Eastbound	118	118	0
	Westbound	128	122	5
U.S. 29 Greenville #2	Eastbound	195.5	200.6	2.6
	Westbound	148.5	159.1	7.1
U.S. 17 Charleston	Eastbound	119.6	105.3	11.9
	Westbound	122.8	116	5.5
U.S. 1 Richland #2	Eastbound	187.5	188.9	0.7
	Westbound	224.5	202	10
U.S. 378 Lexington #1	Eastbound	136	124.7	8
	Westbound	142	143.9	1
U.S. 378 Lexington #2	Eastbound	179	172	3.9
	Westbound	160.6	145	9.8
U.S. 76 Florence	Eastbound	137.1	143	4.3
	Westbound	234.7	258	9.9
S.C. 153 Powdersville	Eastbound	111.5	107.6	3.5
	Westbound	116.4	124.3	6.8

For each corridor, the required number of simulation runs (n) was calculated using the following Eq. 3-1 [12].

$$n = \left(\frac{z_{\alpha/2} * \sigma}{E}\right)^2 \qquad \textit{Eq. 3-1}$$

Where, for a 95% confidence interval, $z_{\alpha/2}$ is 1.96. With different seed numbers, each simulation scenario was run ten times in VISSIM to get the standard deviation (σ). Initially the population standard deviation (σ) and standard error (E) values were not known. It was assumed that the population and the sample standard deviation, derived from ten samples for each corridor, were equal. Running the simulated corridors for ten times, the initial values of σ and E for each corridor were derived. Using this σ and E, the required number of samples (n) for each corridor was obtained. Between the simulation travel time and field travel time, 10% difference was considered acceptable. Thus, the error, E was considered to be 10% of the field-measured average travel time.

3.2.3. What-if Scenario Design

Recall that the four access management strategies of interest in this study are: (i) driveway consolidation, (ii) providing sufficient corner clearance distance from an intersection, (iii) access restriction near signalized intersections, and (iv) non-traversable medians. To test the operational impacts of each of these strategies, four alternative scenarios were developed. Each alternative scenario was evaluated for all simulated corridors. The simulation run time was 75 minutes, which included 15 minutes of 'warm up' time and 60 minutes of data collection. This 60-minute period represented peak hour volumes, as collected in the field. The calibrated base models for both corridors were run for the simulation run time. Travel time, number of stops, delay, and stopped delay across the mainline corridor, as well as for the distance from a driveway to the next downstream intersection of the driveway, and for the distance from the immediate upstream intersection of a driveway to the driveway were collected. These same measures of effectiveness were analyzed for the four alternative scenarios to test each access management strategy, described below.

In order to evaluate the impact of spot improvement, two scenarios were tested for the S.C. 153 Powdersville corridor. The base model was calibrated with the existing traffic count and SCDOT provided signal timing data. The before condition was simulated by recreating the condition before the directional median opening was implemented, as shown in Figure 3-2. The after condition included installation of a directional median. Although the surrounding businesses were not developed in the real-world before implementing the directional median opening, the driveway location and driveway traffic from these businesses were considered while simulating the before scenario to assess the impacts of directional median opening. Impacts were evaluated for driveways where spot improvement occurred and driveways where improvements did not occur.

3.2.3.1.Driveway Consolidation

In order to test driveway consolidation, criteria for determining acceptable spacing needed to be established. The literature review in Appendix A references the different spacing criteria in 36 states. SCDOT's spacing criteria (Figure 3.7 from [18]) were chosen as the spacing to test. In order to alter the corridors to this minimum spacing, driveways were consolidated along the corridor – in other words, certain driveways were closed and their entering and exiting traffic added to nearby driveways to achieve the desired spacing of 325 ft. (for posted speed limit 45 mph). Driveways within the minimum corner clearance were not closed as long as there was adequate spacing to the next driveway. Consideration was given to whether there were side-streets and/or alternate routes from the remaining driveways to the land-uses serviced by the closed driveways. Non-signalized intersections were not closed, and major-traffic generators were given priority to remain 'open.' Signals were not optimized as no turning volumes were altered in this scenario. As an example, driveway closure for two corridors is shown in detail. Figures in Appendix C have been split into segments (Figure C-15 with five segments, Figure C-19 with four segments,) for viewing. These figures (Figure C-14 to Figure C-21) show the driveways that were consolidated for each corridor, and the before and after scenario in VISSIM. The pink markers represent the location of the remaining driveways whereas the green markers represent the driveways that are being consolidated (in the yellow boxes) to form the new driveway. Along S.C. 146 Greenville, the number of driveways in the alternative scenario was reduced from 62 to 28 and the driveway density was reduced from 41 driveways per mile to 19 driveways per mile. Along U.S. 29 Greenville #1, the number of driveways in the resulting alternative scenario was reduced from 66 to 24 and the driveway density from 61 driveways per mile to 22 driveways per mile

3.2.3.2. Access Closure within the Corner Clearance Distance

To test the impact of providing corner clearance from an intersection, a criterion for determining acceptable corner clearance needed to be established, similar to the access spacing scenario. Most state corner clearance standards cited values in the 200-400 foot range. South Carolina's values (Figure 3.7 from [18]) were chosen for testing in this strategy. Driveways that were within the minimum of 325 ft. (for corridors with 45 mph posted speed limit) were closed and their entering and exiting traffic were added to nearby driveways that were located beyond the minimum acceptable corner clearance (325 ft. for corridors with 45 mph posted speed). In many cases, however, the traffic from closed driveways had to be routed to the nearest signal as no other driveways were available. In these cases, the signal splits, cycle length, and coordination were optimized in this scenario. Figures in Appendix C show the driveways which were closed to achieve 325 ft. corner clearance distance and the corresponding driveway or signal to which the traffic was routed, as well as the before and after situation in VISSIM simulation (i.e., Figure C-22 to Figure C-27 for S.C. 146 Greenville and U.S. 29 Greenville #1 corridors).

3.2.3.3.Access Restriction of Selected Driveways

In order to test the effect of restricting access to the selected driveways, some criteria were needed to select which driveways to restrict. Currently, the most common case for restricting access to right-in/right-out occurs when minimum corner clearance requirement cannot be met, and driveways are within the influence area of an intersection. Again, for the sake of consistency, SCDOT's corner clearance standard was used to select driveways for access restriction to right-in/right-out using this commonly recommended value in current practice. SC stipulates that the minimum corner clearance is 325 ft. (for 45 mph posted speed limit) for a full access driveway and 150 ft. for a right-in/right-out driveway. Rather than closing access points, the effect of restricted access was tested by changing all driveways within 325 ft. of an intersection to right-in/right-out (for 45 mph posted speed limit). In other words, all the driveways that were closed and rerouted in the previous scenario, were changed to right-in/right-out access in this scenario. To review which driveways were altered for S.C. 146 Greenville and U.S. 29 Greenville #1 corridors to right-in/right-out, refer to the Figure C-22 to Figure C-27 for S.C. 146 Greenville and U.S. 29 Greenville #1 corridors in Appendix C. For the driveways that had their access restricted to right-in/right-out, the left-in and left-out volumes were redirected using RTUT movements at the nearest feasible signalized intersection. The 'nearest feasible' signalized intersection was determined using the suggested offset distances provided by Lu et al. [19]: 550 ft. on four-lane roads and 750 ft. on six-lane roads. Because signal turning, and through volumes were altered in this scenario, signal optimization of splits, cycle, and coordination was performed.

3.2.3.4.Non-Traversable Medians with Intersection U-turn

To test the operational impact of non-traversable medians, the TWLTL available in the simulated corridors was converted to a raised median, allowing only right-in/right-out access at all driveways. Based on results from the phone interview with state DOT's, in which seven of the twelve states mentioned they would use RTUT to accommodate left turning traffic, the left-in and left-out volumes were redirected using RTUT movements at the nearest feasible signalized intersection. For this study, 'nearest feasible' was determined using the suggested offset distances provided by Lu et al. [19]: 550 ft. on four-lane roads and 750 ft. on six-lane roads. Because signal turning volumes and through volumes were altered in this scenario, signal optimization of splits, cycle, and coordination was performed. Left turn storage lanes were lengthened, and protected left turn phases were added at signals, to accommodate the additional U-turning traffic. In this scenario, the necessary median width – and therefore right-of-way in order to perform U-turns is important to note. The TRB Access Management Manual [1] gives minimum width of median separators by design vehicle. For the Passenger Car design vehicle (P) the minimum total median width required to perform a U-turn is 30 feet (18 ft. separator + 12 ft. turning lane) for four-lane roads and 18 feet (6 ft. separator + 12 ft. turning lane) for six-lane roads.

For example, for the four-lane U.S. 29 Greenville #1 corridor, the existing width of the road (including sidewalks) is roughly 78 ft. With the additional 18 feet of median width necessary, the new required width is 96 ft. For the six-lane S.C. 146 Greenville corridor, the existing width of the road is roughly 90 ft. With the additional six feet of median width necessary, the new required width is 96 ft. For the S.C. 146 Greenville corridor, the change to provide the sufficient turning radius would require a fairly significant widening of the road. However, it appears feasible, in the sense that the buffer does not intrude on any business fronts. There would be major concerns regarding parking, driveway throat lengths, etc. For U.S. 29 Greenville #1, the change is much less significant, and certainly appears feasible, given that the existing three lanes in each direction provide extra turning width for passenger cars. For other corridors, the feasibility of implementing non-traversable median still needs to be studied.

3.2.4. Operational Impact Evaluation Criteria of Access Management Strategies

The operational analysis includes the evaluation of different access management scenarios. For this study, the operational impact was measured for both mainline traffic and driveway traffic. For mainline traffic, the average travel time, number of stops, delay, and stopped delay for both directions were considered as the measures of effectiveness (MOEs). The definition of these MOEs are provided below:

1. Average travel time per vehicle (in seconds): The average time required by a group of vehicles between crossing the same initial intersection/driveway trip generation points and crossing the same destination intersection/driveway trip end points.
2. Average delay per vehicle (in seconds): Average delay is estimated for all vehicles completing the same trip (i.e., starting from the same initial intersection/driveway trip generation points and crossing the same destination intersection/driveway trip end points) by subtracting real time minus the ideal travel time. The ideal travel time is the trip completion time required by a vehicle if no interruption is caused by any surrounding vehicles or signal controls existed along the route.
3. Average stopped delay per vehicle (in seconds): The average standstill time for every vehicle to complete the same trip (i.e., starting from the same initial intersection/driveway trip generation points and crossing the same destination intersection/driveway trip end points).
4. Average number of stops per vehicle: The average number of stops for a group of vehicles completing the same trip (i.e., starting from the same initial intersection/driveway trip generation points and crossing the same destination intersection/driveway trip end points).

Using different random seed numbers, multiple simulation runs were conducted. For different access management what-if scenarios (i.e., driveway consolidation, providing sufficient corner clearance distance from an intersection, access restriction near signalized intersections, and non-traversable medians), the average travel time, delay, stopped delay and number of stops from different runs were measured to compare with the corridors' current access management strategy (i.e., TWLTL for 9 corridors and raised median for U.S. 17 Charleston). The two-sample t-test was applied to compare MOEs of what-if scenarios with the existing TWLTL/raised median scenario. It helps to answer questions whether the MOE is changed in different what-if scenarios. The hypotheses are as follows.

> **H_0:** the means of MOE in the what-if scenarios and the existing TWLTL/raised median scenario are equal

> **H_A:** the means of MOE in the what-if scenarios and the existing TWLTL/raised median scenario are not equal

The null hypothesis, H_0 is rejected, for 0.05 level of significance, if the p-value is less than 0.05.

Depending on whether the variances of the given samples are equal, a different t-test would be used. The F-test was used to test for equality in variances. The hypotheses for F-test are as follows.

> **H_0:** $\sigma_1 = \sigma_2$
> **H_A:** $\sigma_1 \neq \sigma_2$

The null hypothesis, H_0 is rejected, for 0.05 level of significance, if the p-value is less than 0.05.

For the driveway traffic, the travel time, number of stops, delay, and stopped delay were captured for both entering (from the immediate upstream intersection of a driveway to the driveway) and exiting (from a driveway to the immediate downstream intersection of the driveway) driveway traffic. Figure 3-4 shows the right-in[10] and left-in[11] driveway movements (from the immediate upstream intersection of a driveway to the driveway) for Eastbound/EB mainline traffic. Figure 3-5 shows the driveway exiting movements (from a driveway to the immediate downstream intersection of the driveway) for both right-out[12] and left-out[13] driveway movements.

[10] Right-in movements from the immediate upstream intersection to the driveway
[11] Left-in movements from the immediate upstream intersection to the driveway
[12] Right-out movements from the driveway to the immediate downstream intersection
[13] Left-out movements from the driveway to the immediate downstream intersection

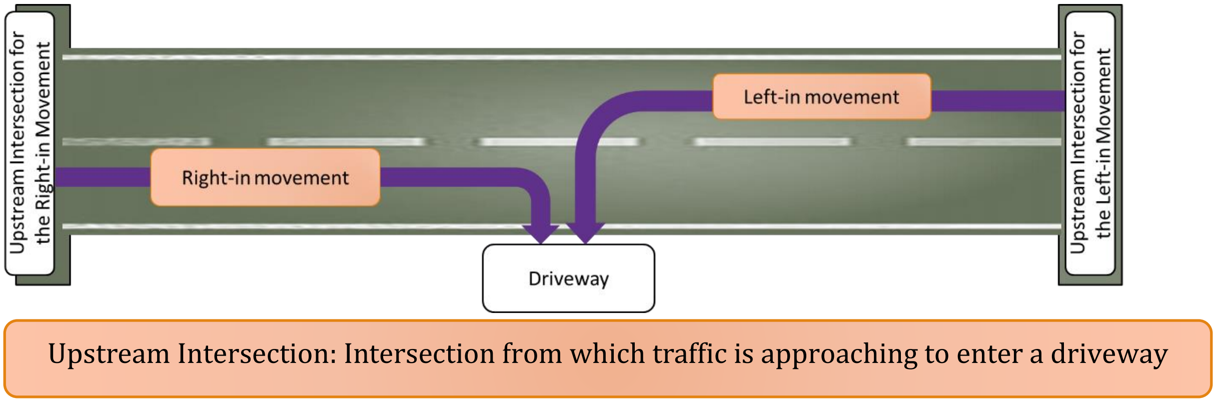

Figure 3-4: Right-in[16] and Left-in[17] Driveway Movements

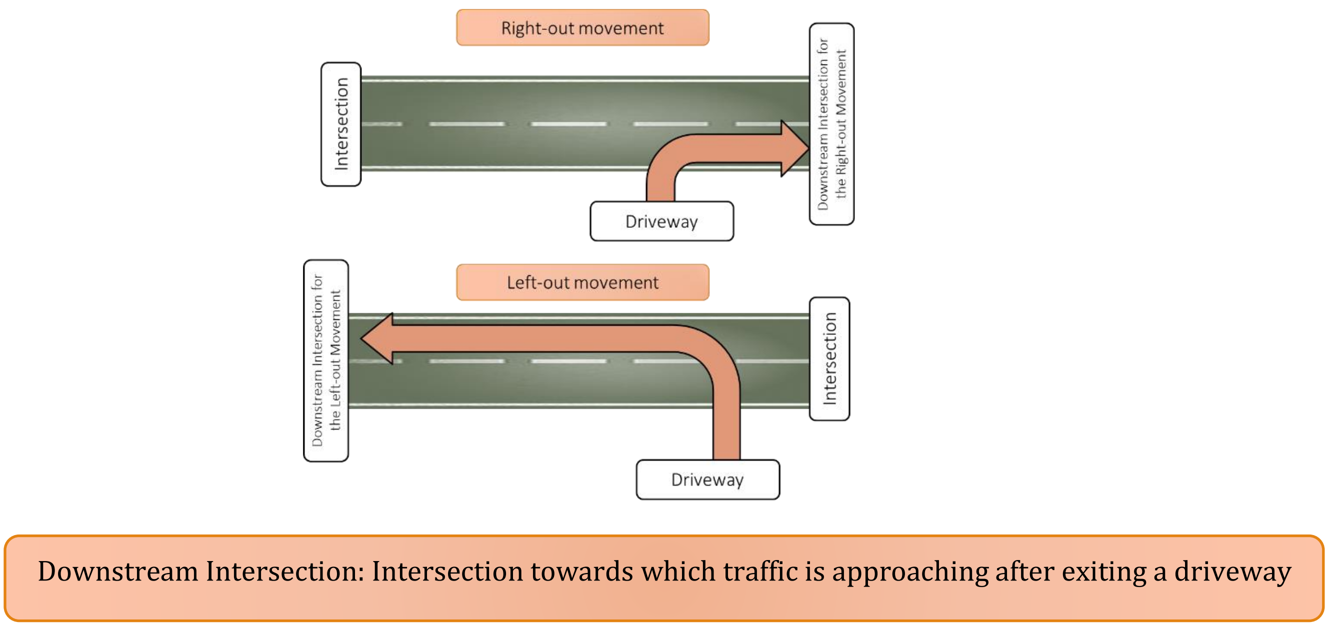

Figure 3-5: Right-out[14] and Left-out[15] Driveway Movements

For all MOEs, the driveway right-in[16], left-in[17], right-out[14], and left-out[15] MOEs (e.g., travel time) were estimated with the weighted MOE (e.g., travel time) equation as shown in the following Eq. 3-2. In this Eq. 3-2, i is the access number, M is the number of access, N is the total vehicle number entering i-th access and T is the corresponding average left-in[17] or right-in[16] travel time associated with N vehicles.

[14] Right-out movements from the driveway to the immediate downstream intersection
[15] Left-out movements from the driveway to the immediate downstream intersection
[16] Right-in movements from the immediate upstream intersection to the driveway
[17] Left-in movements from the immediate upstream intersection to the driveway

$$\text{Driveway travel time} = \frac{\sum_{i=1}^{M} T_i N_i}{\sum_{i=1}^{M} N_i} \qquad \textit{Eq. 3-2}$$

For example, the highlighted sections in Figure 3-6 show corridor segments within two successive signalized intersections for the U.S. 76 Florence corridor. Assuming the number of driveways for the corridor is exactly the same as shown in the figure (i.e., total nine driveways) and considering EB mainline traffic is the right-in[18] driveway traffic, then we can calculate the average travel time for the right-in[18] driveway movement with the following Eq. 3-3.

$$\text{Right-in[18] Driveway (EB) Average Travel Time} = \frac{T1N1 + T2N2 + \cdots + T9N9}{N1 + N2 + \cdots + N9} \qquad \textit{Eq. 3-3}$$

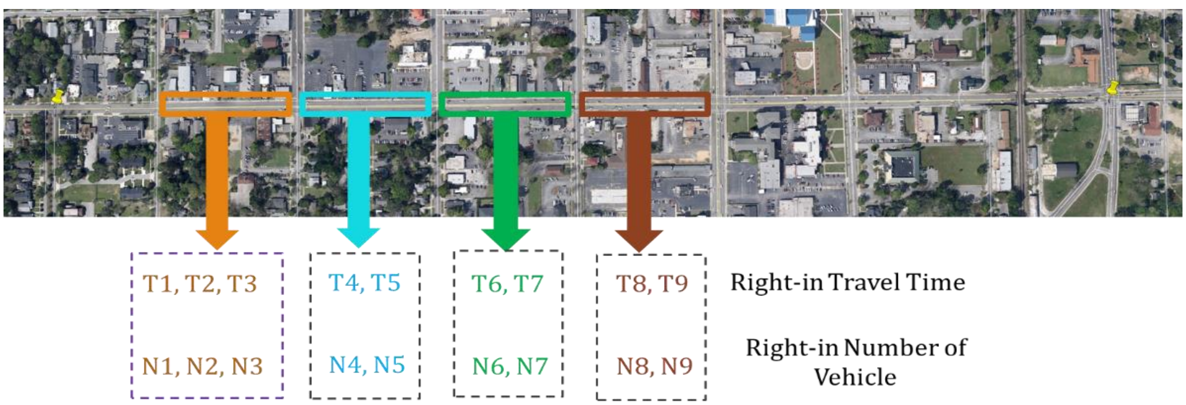

Figure 3-6: Right-in[18] Travel Time for U.S. 76 Florence

3.3 Economic Impact Evaluation Method

3.3.1 Surveys

To examine how businesses and customers perceive the impact of raised medians, different surveys for businesses and customers were developed. These surveys sought to gain insight into the perceptions and attitudes of customers and business owners or managers regarding the general economic, safety and operational impact of raised medians. The questions were developed based on similar surveys found in the literature review [20]–[23].

[18] Right-in movements from the immediate upstream intersection to the driveway

3.3.1.1 Business Survey

Two slightly different surveys were developed for businesses: one for businesses located along NRM corridors and one for businesses located along PIRM and RIRM corridors. For businesses located along NRM corridors, their perception is determined via “what-if” questions such as “what would be the impact on your business gross sales if a raised median was installed in the adjacent corridor?” The survey questions for businesses located along PIRM and RIRM corridors are shown in APPENDIX H. The same questions are asked of businesses located along NRM corridors (Appendix I), with the exception of question two.

3.3.1.2 Customer Survey

Two slightly different surveys were developed for customers, one for those who visit businesses located along RIRM corridors and one for those visit businesses located along PIRM corridors. The survey questions for patrons of PIRM and RIRM businesses are shown in APPENDIX J and APPENDIX K.

3.3.2 Chi-Square Test

In this study, to investigate if two variables are significantly associated or not, the Chi-Square test is used. In this study, it is used to determine the association between business, customer or corridor attributes and perception. Following shows the null hypothesis and alternative hypothesis of this test.

H_0: The two categorical variables (e.g. indicated response of impact of raised medians and the type of business) are independent

H_A: The two categorical variables (e.g. indicated response of impact of raised medians and the type of business) are dependent

To perform this test, two categorical variables are summarized in the contingency table (shown in Table 3-10).

Table 3-10: Layout of a Contingency Table [24]

	Second categorical variable			
First categorical variable	**1**	**.**	***J***	**Total**
1	C_{11}	.	.	R_1
I	.	.	.	R_i
Total	C_1	.	*Cn*	*N*

Then, the χ^2 test statistic is estimated as follows [24].

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad \textit{Eq. 3-4}$$

where

$\chi^2 =$ the test statistic
$O_{ij} =$ the observed count in cell (i, j)
$E_{ij} =$ the expected count in cell (i, j)
r = number of rows
c = number of columns

The expected count in each cell is calculated as follows.

$$E_{ij} = \frac{R_i C_j}{n} \qquad \textit{Eq. 3-5}$$

where R_i and C_j are the totals of row and column, respectively.

The degree of freedom is calculated as follows.

df = (r-1)(c-1) *Eq. 3-6*

where

df = Degree of freedom

The computed test statistic value is compared with the critical value χ^2_α with degree of freedom df at α significance level. If $\chi^2 > \chi^2_\alpha$, then H_0 (i.e., the null hypothesis) is rejected.

In this study, a significance level of 5% was used for Chi-Square test, and the SPSS statistical software (version 22) was used to perform the Chi-Square test.

3.3.3 Post-facto analysis

The two primary techniques often used to analyze the effectiveness of an implemented strategy are before-and-after analysis and post-facto analysis [21]. These two methods are similar, with the only difference being the time period in which the data are collected. The before and after analysis is applicable when data can be collected during two separate time periods – one prior to implementation of a change to the roadway, and another after the change has been completed. The post-facto analysis takes place when only the post-construction data collection is possible because the roadway had already been changed when the study begins. This study used the post-facto technique to assess the actual economic impact of raised medians on sales volume of businesses. The sales volume one year before and three years after the median installation were compared for the analysis.

Sales volume of negatively affected businesses is compared with their control group which consists of either *competitors* or *other branches* of the same business. The competitor group is a collection of competing businesses located along the same corridor of a particular business. Note that at this point, investigation was carried out to determine if the raised median had a negative impact on business or not. A '0% negatively affected businesses' means no business experienced a decrease in sales volume; the control group was not examined in these cases. The information about competing businesses is obtained from the ReferenceUSA database; it provides a list of businesses that are competitors of a specific business. In this study, we selected competing businesses located along the same corridor but do not have raised medians. For certain types of businesses such as banks, competing businesses are not prevalent. In these cases, instead of considering competitors, other branches of that business which are located in other parts of the city are considered. It should be noted that ReferenceUSA reports the same sales volume for some of the businesses examined in this study; this is due to either rounding or lack of data. This limitation should be considered when interpreting the results. The ReferenceUSA database was the only publicly available database that provides business sales volume at the time of this research.

3.3.4 Binary logit model

A binary logit model was developed from the business survey data and data obtained from ReferenceUSA, Google Maps, U.S. Census and SCDOT's website. The logit model is a regression model and is used when the response variable has two possible outcomes [25], [26]. Here, the binary logit model is used to estimate the probability of a business indicating that raised medians will have no negative effect depending on a set of attributes (i.e., explanatory variables) associated with the business and corridor. A technical description of the binary logit model is provided below.

Let X = (x_1, x_2, ... , x_n) be a set of explanatory variables; x_i can be discrete or continuous. Let Y be a binary response variable; Y_i =1 if the trait (i.e., success) is present in observation i. The logit value of the unknown probability is modeled as a linear function [27].

$$\mathrm{logit}\,(\mathrm{Pr}_i) = \ln(\frac{\mathrm{Pr}_i}{1-\mathrm{Pr}_i}) = \beta_0 + \beta_1 x_{i1} + \ldots + \beta_k x_{ik} \qquad \textit{Eq. 3-7}$$

where:
Pr_i= Probability that Y_i =1

Parameters β_j (j = 0,…, k) are estimated through maximum likelihood estimation [28]. The logit coefficient of β_j indicates how much the log-odds changes (i.e., increases if positive and decreases if negative) by every 1-unit increase of the explanatory variable x_{ij}. The following function is referred to as a logistic regression:

$$P(Y_i = 1 \mid X) = \frac{1}{1+e^{-(\beta_0+\beta_1 x_{i1}+\ldots+\beta_k x_{ik})}} \qquad \textit{Eq. 3-8}$$

where:
e=Exponential constant, approximately equal to 2.17

In this study, the response variable, Y, is the response from businesses about the impact of access management on their gross sales; the answer choice was either negative impact or no negative impact. A total of 18 explanatory variables were considered. These variables are related to businesses and corridors and their data were obtained from the survey, ReferenceUSA, Google Maps, U.S. Census and SCDOT's website. The statistical software NLOGIT (version 5) was used to estimate the model. The initial model considered all 18 explanatory variables. Then, a systematic procedure of removing and adding variables was used to find the best set of explanatory variables. Variables were retained in the specification if they have t-statistics corresponding to the 95% confidence level or higher (i.e., p-values less than 0.05).

For each revised model, a likelihood ratio test was used to test the effectiveness of that model. The null hypothesis is that the unrestricted and restricted models are statistically equivalent; the unrestricted model is the previously best model and the restricted model is the revised model. The term restricted implies that one or more variables have been removed from the model. A technical description of the likelihood ratio test is provided below [24].

$$\chi^2 = -2\left[LL(\beta_R) - LL(\beta_U)\right] \qquad \textit{Eq. 3-9}$$

where

$LL(\beta_R) =$ log likelihood of restricted model

$LL(\beta_U) =$ log likelihood of unrestricted model

$\chi^2 =$ Chi-Square statistic (the difference between the parameter numbers in the restricted and unrestricted models = Degrees of freedom)

Although the direction of the effect can be estimated by the sign of the estimated coefficients in the logit model, the marginal effect cannot be estimated. To address this issue and to investigate the impact of the explanatory variables on the response variable, the average partial effects are reported. A partial or marginal effect shows the change in the predicted probability when an independent variable is changed [29]. For continuous variables, it is calculated as follows [30].

$$\frac{\partial E[y \mid X]}{\partial X} = \frac{dF[\beta' X]}{d(\beta' X)}\beta = F'(\beta' X)\beta = f(\beta' X)\beta \qquad \textit{Eq. 3-10}$$

where

$X =$ vector of explanatory variables,

$\beta =$ vector of parameter estimates,

$F =$ cumulative distribution function, and

$f =$ probability density function.

The marginal effects for dummy variables are calculated as follows [30].

$$\Pr[y=1 \mid z=1]-\Pr[y=1 \mid z=0]$$ *Eq. 3-11*
$$=F(\beta^{'}X+\alpha z \mid z=1)-F(\beta^{'}X+\alpha z \mid z=0)$$
$$=F[\beta^{'}X+\alpha]-F[\beta^{'}X]$$

3.3.5 Safety analysis

Published literature [31] points to overall positive safety effects from the raised median. These effects happen due to decreases in conflict points and greater separation of opposing flows. This section describes the crash analysis performed at three corridors in SC; Corridors 11, 12 and 13. This analysis provides an estimation of the safety impact of raised medians of corridors after the construction period. SCDOT provided crash data that occurred at these study locations. Since data were available only from 2011 to 2015, Corridors 11, 12 and 13, with the construction period between 2012 and 2014 were included in this analysis.

There are two alternatives when drivers are required to make left-turn to a driveway/side street: (1) make a direct left-turn from the main street to driveway or side street when the median is TWLTLs or driveway/side street located at opening of raised medians (Figure C-28.a in Appendix C), and (2) make a U-turn at a downstream median opening or signalized intersection followed by a right-turn to the driveway or side street (Figure C-28.b in Appendix C). When a raised median is installed, many left turns to driveways along a roadway are restricted. Therefore, the drivers must be accommodated to make a U-turn either at the next median opening or signalized intersection or. This leads to the shift of the mid-block conflict to the next median openings or at signalized intersections. As a result, new conflict points are created along the corridors.

To study the safety impact of installing raised medians, the crash rates at new conflict points along the selected corridors were investigated. Using Google Maps, all driveways that were blocked after installation of a raised median were identified. Then, the nearest signalized intersections or median openings were considered as new conflict points. Finally, crash rates before and after construction period are investigated at these new conflict points.

The crash rate factor can be calculated as follows.

$$\text{RMEV} = \frac{\text{A} \times 1{,}000{,}000}{\text{V}} \qquad \textit{Eq. 3-12}$$

where

RMEV = crash rate per million entering vehicles

A = number of crashes, total or by type occurring in a single year at the location

V = ADT × 365

ADT = average daily traffic entering intersection

The two-sample t-test was applied to compare crash rate before and after raised median installation. It helps to answer questions whether the average crash rate is changed after implementing of the raised median. The hypotheses are as follows.

H_0: the means of RMEV in the year before and after median installation are equal

H_A: the means of RMEV in the year before and after median installation are not equal

The null hypothesis, H_0 is rejected, for 0.05 level of significance, if p-value is less than 0.05.

Depending on whether the variances of the given samples are equal, a different t-test would be used. The F-test was used to test for equality in variances. The hypotheses for F-test are as follows.

H_0: $\sigma_1 = \sigma_2$

H_A: $\sigma_1 \neq \sigma_2$

The null hypothesis, H0 is rejected, for 0.05 level of significance, if p-value is less than 0.05.

3.4 Summary

This chapter discusses the methods adopted for analysis in this project. To evaluate the operational, economic and safety impacts of access management alternatives, several S.C. corridors were chosen and analyzed. State DOTs were surveyed and interviewed, and local businesses and customers were surveyed. The following chapters will discuss the survey analysis and findings from the simulations and statistical analysis.

CHAPTER 4 OPERATIONAL IMPACT ASSESSMENT

4.1 Simulation Study: Sample Size Estimation

The number of simulation runs needed for the simulated corridors were calculated using Eq. 3-1, and the results are shown in Table 4-1. For each corridor, the resulting MOEs were calculated for each corridor by averaging the MOE output from the total number of simulation runs.

Table 4-1: Number of Simulation Run for Each Corridor

Corridor	Number of Simulation Runs
S.C. 146 Greenville	24
U.S. 176 Richland	11
U.S. 1 Richland #1	11
U.S. 29 Greenville #1	12
U.S. 29 Greenville #2	13
U.S. 17 Charleston	5
U.S. 1 Richland #2	5
U.S. 378 Lexington #1	6
U.S. 378 Lexington #2	30
U.S. 76 Florence	11
S.C. 153 Powdersville	51

4.2 Operational Impact of What-if Access Management Scenarios

4.2.1 Mainline traffic

As discussed in Section 3.2.4, four MOEs were considered for evaluation of different what-if scenarios (driveway consolidation, providing sufficient corner clearance distance from an intersection, access restriction near signalized intersections, and non-traversable medians), which are shown in Figure 4-1. In this section, the findings for the mainline traffic are discussed for the corridors where different corridor-wide access management scenarios were evaluated. All the detail data supporting the analysis are provided in 0. The mainline vehicle average travel times for both directions in all ten corridors were studied. Geometric characteristics (e.g., number of driveways, intersection turn lanes), traffic characteristics (e.g., driveway exiting and entering traffic volume) and land-use pattern vary in two directions. Due to these disparities, the travel time data varied in each direction for each what-if scenario. The impacts of the different access management strategies varied from one site to the other.

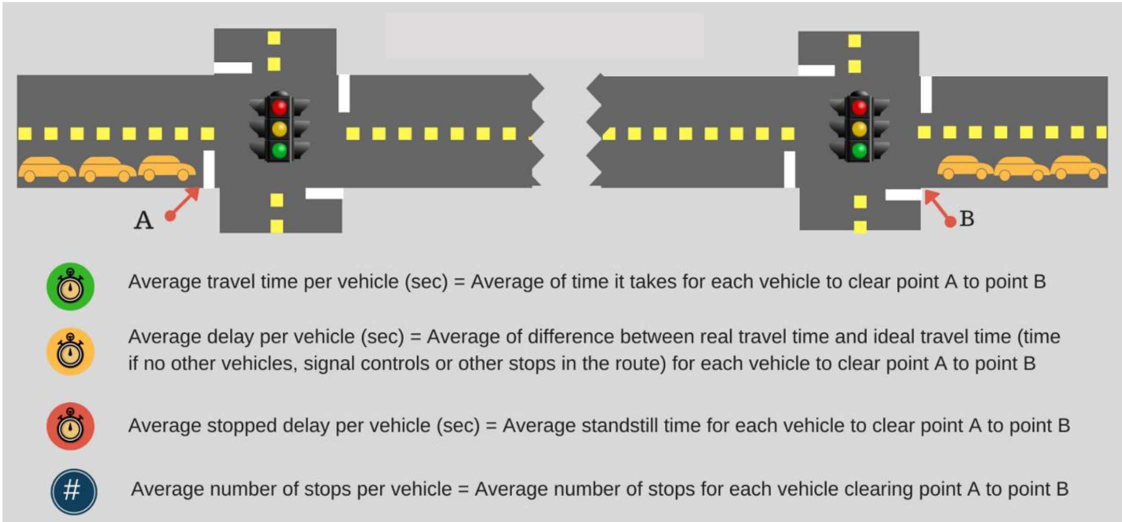

Figure 4-1: Measures of Effectiveness for Operational Analysis

The findings from the travel time analysis for mainline traffic can be found in Table 4-2. In order to compare the different access management strategies, the traffic signal timing was optimized using Synchro for the eight corridors that did not have adaptive signal control. For the two corridors with adaptive signal control (U.S. 17 Charleston and U.S. 1 Richland 1), the existing conditions, a raised median in one corridor and TWLTL in the other corridor, were simulated with the adaptive ACS-Lite traffic control algorithm.

Table 4-2: Average Mainline Travel Time for Different Scenarios (Simulation Result)

Corridors	TWLTL	Non-traversable Median		Driveway consolidation		Corner clearance from an intersection		Access restriction	
	sec/veh	sec/veh	%**	sec/veh	%**	sec/veh	%**	sec/veh	%**
S.C. 146 Greenville	212*	227	7.18	208	-1.75	216	2	221	4.45
U.S. 176 Richland	125*	142	13.91	123	-1.41	130	4.28	129	2.75
U.S. 1 Richland #1	140*	166	17.90	142	0.90	159	-8.5	158	12.84
U.S.29 Greenville #1	113*	128	14.15	111	-1.30	112	-0.15	109	-3.51
U.S. 29 Greenville #2	167*	167	0.30	182	9.38	154	-7.63	167	-0.13
U.S. 17 Charleston	-	110*	-	105	-4.5	128	16.4	-	-
U.S. 1 Richland #2	146*	151	3.42	146	0	142	-2.74	-	-
U.S. 378 Lexington #1	133*	134	0.75	134	0.75	134	0.75	133	0
U.S. 378 Lexington #2	140*	151	7.56	141	0.58	141	1.03	131	-6.53
U.S. 76 Florence	144*	165	14.37	145	0.62	142	-1.49	139	-3.14

** Existing access management strategies on corridors*

***Percent change (%) compared to existing Condition*

The percent changes of average mainline travel time, compared the current access management strategy with TWLTL for nine corridors and with raised medians for U.S. 17 Charleston corridor, were calculated as shown in Table 4-2. A positive value indicates the extent to which the average travel time increased compared with the existing condition with

TWLTL/raised median, whereas a negative value indicates the extent of average travel time reduction. A statistical significance test was conducted at a 95% confidence interval.

Findings from the analysis suggest that the mainline travel time increased for all test corridors when converting a TWLTL into a non-traversable median. For U.S. 29 Greenville #2 and U.S. 378 Lexington #1, the increase was almost negligible. The highest increase (17.9%) was observed for the U.S. 1 Richland #1 corridor. Another strategy studied was driveway consolidation. Implementing this strategy, nine corridors (with TWLTL or raised medians) experienced either travel time reduction or negligible travel time increases (i.e., less than 1%) when compared to the condition without consolidating driveways. Based on the analysis, both corner clearance distance from an intersection and access restriction impacts were found to vary from site to site. This finding suggests the necessity of site-specific operational analysis for corner clearance and access restriction.

The analysis also included the study of mainline traffic average delay, number of stops and stopped delay under different conditions as shown in Table D-2 in 0. For U.S. 17 Charleston, the comparison was conducted relative to a raised median. Seven out of nine corridors resulted in a significant increase in delay (up to 68%), stopped delay (up to 96%) and number of stops (up to 62%) due to a raised median when compared with the TWLTL. In the driveway consolidation scenario, by minimizing the number of access points per mile, the number of potential conflicts or stops due to driveway traffic can be reduced. However, diverting the driveway traffic from multiple access points to one access point can affect the mainline traffic by increasing queue length for increased driveway entering vehicles. Among ten corridors, the driveway consolidation scenario changed the delay significantly in four corridors when converted from the condition where there was no driveway consolidation. This indicates that delay reduction for the driveway consolidation strategy is site-specific, and SCDOT needs to conduct site-specific evaluation for driveway consolidation analysis.

The simulation analysis shows that for four corridors, mainline traffic experienced less number of stops, delay, and stopped delay in the access restriction scenario compared against the corner clearance (i.e., providing sufficient distance from an intersection) scenario. These results imply that rather than fully closing the access, allowing right-in/right-out can lead to less number of stops and delay. With full closure of driveways, delay was on average 6% higher than the condition having driveways with full access. With right-in/right-out driveways, delay was on average 7% lower than the condition having driveways with full access. With full closure of driveways, number of stops was on average 7% higher when compared with the condition having driveways with full access. Finally, right-in/right-out results in 9% fewer stops on average than the condition having driveways with full access.

4.2.2 Driveway Traffic

4.2.2.1 Driveway Entering Traffic

The operational evaluation for the driveway-entering traffic is discussed in this subsection. An evaluation was conducted for the right-in[19] driveway traffic, when the mainline traffic performs the right-in[19] maneuver, as shown in Figure 4-2, to enter driveways. Data supporting the analysis for driveways entering traffic are provided in 0. The percent change in travel time was compared with TWLTL for nine corridors and raised median for U.S. 17 Charleston (as presented in Table D-4 in 0). The intersection U-turn scenario increased the right-in[19] travel time for driveway traffic (up to 37%) while converted from TWLTL, while for one corridor (i.e., S.C. 146 Greenville) it was decreased by less than 3%. Among the four alternatives, driveway consolidation, once converted from the condition where there was no driveway consolidation, decreased travel time for right-in[19] driveway traffic in eight corridors. For six corridors, providing sufficient corner clearance distance

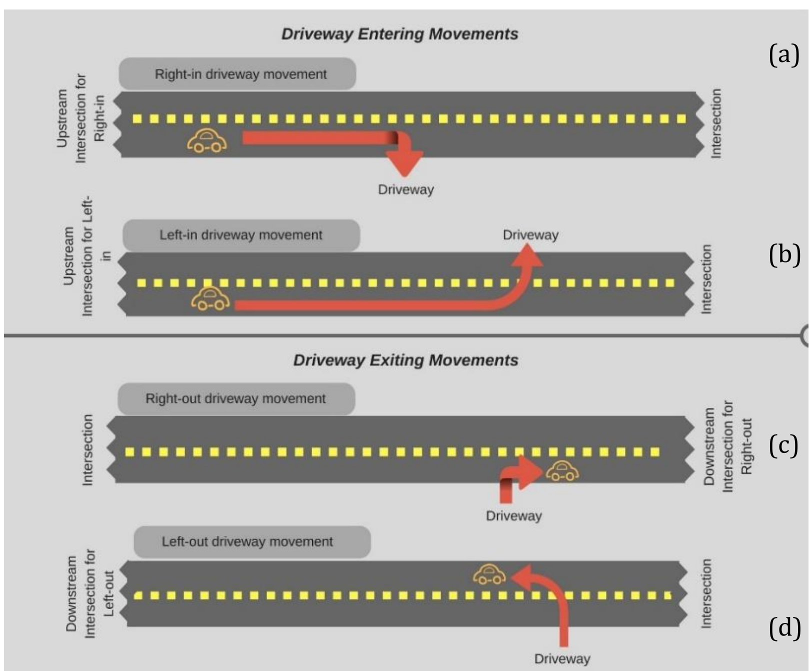

Figure 4-2: Driveway Entering and Exiting Movements

[19] Right-in movements from the immediate upstream intersection to the driveway

from an intersection decreased the travel time for right-in[19] traffic compared to the access restriction.

The simulation findings of the MOEs studied for the right-in[20] movements, as shown in Figure 4-2 (a), for driveway traffic are also summarized in as shown in Table D-5 in 0. Generally, driveway consolidation created less average delay (up to 24% reduction for the U.S. 1 Richland #2 corridor), stopped delay (up to 90.7% reduction for the U.S. 1 Richland #2 corridor) and number of stops (up to 73% reduction for the U.S. 1 Richland #2 corridor) than that of the intersection U-turn. For eight corridors, the access restriction scenario produced less number of stops, delay, and stopped delay compared to the corner clearance (i.e., providing sufficient distance from an intersection) alternative. For one corridor, U.S. 29 Greenville #1, both corner clearance (i.e., providing sufficient distance from an intersection) and access restriction, produced similar increase changes in all three MOEs (i.e., number of stops, delay, and stopped delay). In general, among the four different what-if scenarios (i.e., non-traversable median, access restriction, providing sufficient corner clearance distance from an intersection and driveway consolidation), access restriction reduced delay for right-in[20] driveway traffic, when converted from the condition (with TWLTL or raised median) where there was no access restriction, for three of the study corridors.

A similar evaluation was conducted for the left-in[21] driveway traffic. As shown in Figure 4-2 (b), the analysis was conducted for traffic entering driveways that use a left-turn maneuver to enter the driveway. From the analysis, it was observed that the travel time for left-in[21] driveway traffic increased for both non-traversable median and access restriction scenarios as shown in Table D-6 in 0. In both scenarios, the left-turn-in[21] and left-turn-out[22] was closed for specific driveways, so driveway entering vehicles needed to make a U-turn in the signalized intersection located at the nearest feasible distance, thereby increasing the travel time. The driveway consolidation scenario, while converted from the condition where there was no driveway consolidation, improved the travel time for nine of the corridors, and the improvement varies from as low as 4% to as high as 54%. Corner clearance (i.e., providing sufficient distance from an intersection) modification improved the travel time for

[20] Right-in movements from the immediate upstream intersection to the driveway
[21] Left-in movements from the immediate upstream intersection to the driveway
[22] Left-out movements from the driveway to the immediate downstream intersection

left-in[21] driveway traffic in six corridors. It was observed that for three corridors, percent changes in travel time varied between driveway consolidation and corner clearance strategies (providing sufficient distance from an intersection) for left-in[23] driveway traffic. These corridors were U.S. 1 Richland #1, U.S. 1 Richland #2, and U.S. 17 Charleston. In the driveway consolidation scenario, driveway density per mile was reduced, hence entering left-in[23] driveway traffic had fewer access points for these three corridors. In the corner clearance scenario (providing sufficient distance from an intersection), driveways within the intersection influence area were closed and the entering and exiting vehicles from the affected businesses were diverted to the nearest driveway outside of the intersection influence area. When diverting traffic from multiple driveways to one driveway, the left-in[23] driveway traffic will rise which can increase the entering vehicle travel time. This increase in entering travel time was observed for left-in[23] traffic in the U.S. 1 Richland #1 corridor. For the U.S. 1 Richland #2 corridor, a limited number of driveways were closed, and the travel time change (1.5%) was negligible when converted from driveways with full access. In the third corridor, U.S 17 Charleston, the base condition was a non-traversable raised median. In this corridor, the left-in[23] driveway traffic needed to make U-turn at the next signalized intersection to enter any driveway. In the corner clearance scenario (including the raised median), driveways within the intersection influence area were closed, and traffic was diverted to the driveways which were located more than 325 ft. (for corridors with 45 mph posted speed limit) from the intersection. Due to this diversion, the left-in[23] traffic faced higher travel time (9% increase) while restricting access within the intersection influence area compared to the base condition of driveways with full access in the intersection influence area. Based on the analysis for other three MOEs (i.e., average number of stops, delay, and stopped delay), for most of the corridors, non-traversable medians increased average number of stops, delay, and stopped delay while converted from TWLTL as shown in Table D-7 in 0. The driveway consolidation scenario reduced the average delay per vehicle in five corridors, whereas the corner clearance (i.e., providing sufficient distance from an intersection) reduced average delay in three corridors.

[23] Left-in movements from the immediate upstream intersection to the driveway

4.2.2.2 Driveway Exiting Traffic

Driveway exiting travel time results for all ten corridors in different what-if scenarios are discussed in this subsection. The right-out[24] driveway travel time refers to the travel time required by the driveway traffic when vehicles are taking the right-out maneuver, as shown in Figure 4-2 (c). The average right-out[24] driveway travel time and the percent change of travel time for different access management strategies were calculated. Positive values indicate that the travel time increased compared to the TWLTL for nine corridors and compared to raised median for U.S. 17 Charleston corridor, whereas negative values indicate that the average travel time decreased. As shown in Table D-8 in 0, it is observed that the driveway consolidation scenario increased travel time for right-out[24] driveway traffic in six study sites, followed by the corner clearance scenarios (i.e., providing sufficient distance from an intersection) where average travel time increased for five test corridors. After calculating the percent change of average delay, stopped delay and number of stops for right-out[24] driveway traffic, as shown in Table D-9 in 0, several conclusions were made. In the corner clearance scenario (i.e., providing sufficient distance from an intersection), the average delay increased for six corridors and stopped delay increased in seven corridors when compared with driveways with full access in the intersection influence area. For both non-traversable median and driveway consolidation scenarios, the delay increased for five test corridors. Once converted from TWLTL, the non-traversable median increased the number of stops for right-out[24] driveway traffic in eight corridors.

Similar analysis was conducted for the left-out[25] driveway traffic, as presented in Figure 4-2 (d). The findings as presented in Table D-10 in 0 indicate that, compared to the TWLTL, the non-traversable median scenario increased the travel time for all corridors, and the access restriction scenario increased travel time for left-out[25] driveway traffic in seven of the nine corridors. This occurred because driveway vehicles that were supposed to take left-out[25] from driveways in the existing scenario with TWLTL instead took a U-turn in the next feasible intersection. Operational evaluation results for number of stops, delay, and stopped delay for all 10 corridors were also calculated for the left-out[25] driveway traffic as shown in Table D-11 in 0. The positive percentage indicates an increase in MOEs compared with the

[24] Right-out movements from the driveway to the immediate downstream intersection
[25] Left-out movements from the driveway to the immediate downstream intersection

TWLTL for 9 corridors and compared to raised median for the U.S. 17 Charleston corridor, whereas the negative value indicates the reduction. For non-traversable medians, the delay and number of stops increased for eight corridors among nine corridors. In the access restriction scenario, the delay was increased for six corridors and the number of stops was increased for seven among eight corridors. The delay changes for the driveway consolidation scenario varied by corridors. This finding suggests that the delay due to driveway consolidation for a corridor needs to be investigated on a case-by-case basis.

4.3 Operational Analysis of Spot Improvements

Different types of spot improvement projects are common in South Carolina. The motivation behind implementing any specific spot improvement project is to address safety and operational issues in any particular driveway or a set of driveways. To evaluate the operational impacts of spot improvement projects, simulation was conducted to study both before and after conditions of the S.C. 153 Powdersville corridor. For mainline traffic, as shown in Table D-12 in 0, it was found that the operational condition changes in the before spot improvement condition were negligible compared to the after-spot-improvement condition (i.e., less than 1% change). For driveways without spot improvements, the changes were less than 5% except for the stopped delay in the left-in[26] movements of driveway traffic (10% change).

The two-sample t-test was conducted to find out whether or not the spot improvement significantly changed the operational conditions in the after scenario with spot improvement compared to the before scenario without spot improvement. It was found that the spot improvement did not affect operational conditions of mainline and driveway (i.e., driveway without improvement) traffic. In addition, the travel time changes for driveway entry traffic (for driveways with spot improvement) were found not significant (compared to before scenario without spot improvement) at 95% confidence level. However, for driveways where improvements were made, the left-in[26] and left-out[27] driveway travel time, delay and stopped

[26] Left-in movements from the immediate upstream intersection to the driveway
[27] Left-out movements from the driveway to the immediate downstream intersection

delay were found to be lower in the before condition compared to the after spot improvement condition.

4.4 Summary

This chapter discusses the operational impact of different what-if scenarios evaluated for corridor-wide access management strategies as well as spot improvement projects. First, the required sample size for simulation runs are estimated and, using this sample size, the calibrated simulation models were run to calculate the average impact. Four MOEs (i.e., travel time, number of stops, delay, and stopped delay) were used to compare the benefits of alternative scenarios. As shown below, different alternative scenarios have different operational impacts on the mainline traffic, as well as on the driveway entering and exiting traffic. Based on these findings, policy suggestions have been developed (discussed in Chapter 6).

- Non-traversable medians increased mainline travel time (up to about 18%) and mainline stopped delay (up to about 96%) compared to Two Way Left Turn Lanes. These findings agree with a previous study [32], which found that vehicles performing RTUT at signalized intersections faced more delay than those vehicles making DLTs.
- An alternative to fully closing driveways at the intersection influence area, allowing a right-in/right-out driveway, can lead to decreased number of stops and delay for the mainline traffic when compared to fully closing access.
- Driveway consolidation decreased the mainline traffic travel time by as much as 5%. Prior research [33] also found that reducing driveways will increase average speed and minimize driveway delay, and driveway queuing.
- Providing corner clearance from an intersection following the SCDOT ARMS manual standards decreased travel time for the right-in[28] and left-in[29] driveway traffic up to about 53% and 56%, respectively when compared to an intersection without corner clearance implementation.
- In general, among the four different what-if scenarios (i.e., non-traversable median, access restriction, providing corner clearance distance and driveway consolidation), access restriction (i.e., restricting left-turn movements) reduced delay for right-in[30]

[28] Right-in movements from the immediate upstream intersection to the driveway
[29] Left-in movements from the immediate upstream intersection to the driveway

driveway traffic in three corridors compared to the existing conditions where driveways have full access.

CHAPTER 5 ECONOMIC AND SAFETY IMPACT ASSESSMENT

5.1 Business Impact through Post-Facto Analysis

The results of the post-facto analysis for the seven corridors are provided in Table E-1 in 0. The sales volume of affected businesses and businesses in the control group were obtained from the ReferenceUSA database. Note that when the percentage of negatively affected businesses is 0%, the control group was not examined and is indicated as "NA" in Table E-1 in 0. Due to the unavailability of the sales volume data after 2016, the post-facto analysis could not be performed for Corridor 17 for the second and third year after the raised median was installed as indicated by "–" in Table E-1 in 0.

The results of the post-facto analysis for Corridor 9 indicated that none of the businesses affected by the raised median noted a decrease in sales volume one year after installing the raised median. However, 57% of the affected businesses did experience a decrease in sales volume in year 2 and 3 after installing the raised median. To determine whether the reason for the decrease in sales volume is because of the raised median installation, the control group was examined. It can be seen in Table E-1 in 0 that 94% of the businesses in the control group faced a reduction in sales volume in year two and three after the raised median was installed.

The results of Corridor 10 analysis indicated that only 8% of the affected businesses experienced a decrease in sales volumes in year 1, 2 and 3 after installing the raised median. For the control group, 100% of the businesses experienced a decrease in sales volume during the same time frame. For Corridors 11 and 12, 50% of the affected businesses faced a reduction in sales volume in year 1 and 2 after the raised median was installed and only 25% experienced a decrease in sales volume in year 3 after the raised median was installed. For the control group, 100% of the businesses faced a reduction in sales volume during the same time frame. For Corridors 13 and 14, none of the businesses affected by the raised median experienced a decreased in sales volume in year 1, 2 and 3 after the raised median was installed. Lastly, the results of Corridor 17 analysis indicated that only 4% of the affected businesses experienced a decrease in sales volumes in year 1 after the raised median was installed. For the control group, 17% of the businesses experienced a decrease in sales volume during the same time frame.

In summary, the results of the post-facto analysis indicated that the sales volume decrease of the affected businesses was similar to that of businesses in the control group. This finding suggests that the installed raised median was not the reason the affected businesses experienced a reduction in sales volume. The local and regional macroeconomics may have contributed to the decrease in sales volume of the affected businesses and their competitors.

5.2 Analysis of Survey Responses

5.2.1 Business Survey Results

A survey was developed and conducted to assess the perception of businesses affected by access management strategies in SC. Participants in the business survey were business owners or managers of businesses along the study corridors. A total of 77 business owners and managers completed the survey. Table E-2 in 0 provides information about their businesses.

Of the business participants, 24 (31%) were located along PIRM corridors, 20 (26%) are located along RIRM corridors, and 33 (43%) were located along NRM corridors. In this study, destination businesses were defined as those with more than 55% of planned customers, whereas pass-by businesses were defined as those with less than 55% of planned customers. Of the business participants, 42 (55%) were destination businesses, and 35 (45%) are pass-by businesses. Businesses with less than 100 customers per day were defined as small-sized and businesses with more than 100 customers per day were defined as large-sized. Of the business participants, 36 (37%) were small-sized, and 41 (53%) were large-sized. Of the business participants, 44 (57%) had their busiest time occurring during the peak hours (8-10 AM and 4-6 PM), and 33 (43%) had their busiest time occurring during the off-peak hours.

The business owners and managers were surveyed about the effect of raised medians on their business, traffic operations and safety. They were asked whether raised medians made (or will make) the following factors worse, better or have no effect.

- Average number of customers per day
- Gross sales

- Customer satisfaction
- Delivery convenience
- Traffic congestion
- Traffic safety
- Property value

If the answer selected is "worse," it indicated raised medians had (or will have) a negative impact, whereas better or the same are viewed as no negative impact. Figure E-1 in 0 presents the survey responses.

As presented in Figure E-1 in 0, 60% of business respondents indicated that raised medians had, or will have, a negative effect on the average number of customers per day, 52% indicated it had (or will have) a negative impact on gross sales, 69% indicated it had (or will) negatively impact customer satisfaction, 68% indicated it had (or will have) a negative impact on the delivery convenience, 57% indicated it had (or will have) a negative effect on traffic congestion, 47% indicated it had (or will have) a negative effect on traffic safety, and 45% indicated it had (or will have) a negative impact on property value. From these results, it can be concluded that in regard to the effect of raised medians, except for traffic safety and property value, a majority of the businesses believed that raised medians had (or will have) a negative impact.

Table E-3 shows a detailed summary of the responses by business size, business type, corridor types and busiest hours of the day. As shown in Table E-3 in 0, businesses along RIRM corridors indicated that raised medians negatively affected all factors, when compared with businesses located along PIRM corridors. Similarly, those businesses that fall into the categories of small-sized, pass-by, and peak hour businesses, indicated that raised medians had negatively affected, or will negatively affect all factors. Lastly, a higher percentage of businesses located along NRM corridors indicated that raised medians would negatively affect all factors when compared with those located along PIRM corridors.

Businesses were asked to rank (i.e., on a scale of 1 to 6) the following factors they believed their customers considered when selecting a business (with "1" being the most important).

- Travel Distance

- Hours of Operation
- Customer Service
- Product Quality
- Product Price
- Accessibility to Stores

Figure E-2 in 0 shows a summary of the response to this question. As presented in Figure E-2 in 0, only 13% of businesses identified accessibility to stores as their customers' first priority and 54% ranked it as 4th, 5th and 6th most important. Although 60% of businesses indicated that raised medians had (or will have) an adverse effect on the average number of customers per day, only 13% indicated that accessibility is the most important factor considered by customers.

Table E-4 in 0 shows a detailed summary of the responses regarding accessibility to stores. A higher percentage of small-sized businesses (22%), as opposed to large-sized businesses (5%), believed that their customers value accessibility greatest in selecting a business. A higher percentage of pass-by businesses (17%), as opposed to destination businesses (10%), ranked accessibility to stores as the most important factor. Although 89% and 80% of pass-by businesses indicated that raise medians had (or will have) a negative impact on the average number of customers and gross sales (as shown in Table E-3 in 0), respectively, only 17% of them ranked accessibility to stores as the most important factor considered by customers. A higher percentage of businesses located along PIRM corridors (17%) and RIRM corridors (20%), as opposed to businesses located along NRM corridors (6%) ranked accessibility to stores as the most important factor considered by customers. A higher percentage of businesses with their busiest times occurring during the on-peak hours (25%), as opposed to businesses with their busiest times occurring during the off-peak hours (5%) ranked accessibility to stores as the most important factor considered by customers. These perceptions are consistent with those expressed by small-sized, pass-by, peak hour businesses.

5.2.2 Chi-square Test Results of Business Survey

To determine if there is an association between the business attributes and the indicated impact of raised medians the Chi-Square test for independence was used. Specifically, it is used to answer the following hypothesis.

H_0: Indicated response of impact of raised medians is independent of the type of business/size of business/type of corridor/busiest hours of the day

H_A: Indicated response of impact of raised medians is not independent of the type of business/size of business/type of corridor/busiest hours of the day

The null hypothesis, H_0 is rejected, If 0.05 significance level, if the p-value is less than 0.05. Table E-5 in 0 presents the results of Chi-Square test.

With the exception of three cases (their p-values are shown in bold in Table E-5 in 0), all null hypotheses are rejected. The rejection of a null hypothesis implies a statistically significant association. In this study, there is a statistically significant association between the size of the business and their indicated response regarding the impact of raised medians on the average number of customers per day. In other words, the small-sized and large-sized businesses had indicated different experiences on the effect of raised medians on the average number of customers per day. If it is not rejected, then there is no association. For example, there is no association between the type of business and their indicated response regarding the impact of raised medians on customer satisfaction. Destination businesses and pass-by businesses indicated similar experience on the effect of raised medians on customer satisfaction.

The following summarizes key findings based on the survey results (summarized in Table E-3 in 0) and the Chi-Square test results.

- A higher percentage of small-sized businesses, as opposed to large-sized businesses, indicated that raised medians negatively affected, or will affect, all factors (i.e., average number of customers per day, gross sales, customer satisfaction, delivery convenience, traffic congestion, traffic safety and property value). This finding suggests that smaller businesses are more vulnerable to the impact of raised medians; that is, a small change in the number of customers has a big impact on the success of their businesses.

- A higher percentage of pass-by businesses, as opposed to destination businesses, indicated that raised medians negatively affected, or will affect, average number of customers, gross sales, delivery convenience, traffic congestion, traffic safety and property value. This finding suggests that pass-by businesses rely more on easy access to their businesses.
- A higher percentage of businesses located along NRM corridors as opposed to those businesses located along PIRM indicated that raised medians negatively affected the average number of customers, gross sales, customer satisfaction, delivery convenience and property value. This finding suggests that the impact of raised medians is perceived to be more negative than it actually is.
- A higher percentage of businesses located along RIRM corridors as opposed to those businesses located along PIRM indicated that raised medians negatively affected the average number of customers, gross sales, customer satisfaction, delivery convenience and property value. This finding suggests that despite an initial negative perception of raised medians, in the long run, businesses can have a positive effect due to the improved traffic operations and safety, and thereby, serves as an attraction to customers.
- A higher percentage of businesses with their busiest times occurring during the peak traffic hours, as opposed to businesses with their busiest times occurring during the off-peak hours, indicated that raised medians negatively affected all factors (i.e., average number of customers per day, gross sales, customer satisfaction, delivery convenience, traffic congestion, traffic safety and property value). This finding suggests that businesses with their busiest times occurring during the peak hours will experience more negative impact because raised medians will add travel time and make access more difficult for customers, particularly during the peak hours.

5.2.3 Customer Survey Results

Participants in the customer survey are customers of those businesses along RIRM and PIRM corridors. A total of 201 customers participated in the survey.

Among the customer participants, 97 (48%) are male and 104 (52%) are female. Of the customer participants, four (2%) are under 18 years old, 97 (48%) are 18-29, 47 (24%) are 30-44, 36 (18%) are 45-59 and 17 (8%) are above 60. Of the customer participants, 96 (48%)

are customers of destination businesses and 105 (53%) are customers of pass-by businesses. According to the type of customers' visit, customers are classified to planned and passing by customers. Of the customer participants, 144 (72%) are planned customers and 57 (28%) are pass-by customers. Of the customer participants, 112 (56%) are surveyed along PIRM corridor and 89 (44%) are surveyed along RIRM corridor. Figure E-3 in 0 presents these data graphically.

In order to compare business and customer perspectives, customers were surveyed using similar questions about the impact of raised medians on businesses, traffic operations and safety. They were asked whether raised medians made the following factors worse, better or the same.

- Access to business
- Customer satisfaction
- Traffic congestion
- Traffic safety

If the answer selected is "worse", it is viewed that raised medians had a negative impact, whereas better or the same are viewed as no negative impact. Figure E-4 in 0 presents the response to this survey question.

As presented in Figure E-4 in 0, 63% of customers indicated that raised medians had a negative impact on access to businesses, 46% indicated it had a negative impact on traffic congestion, 33% indicated it had a negative impact on safety, and 27% indicated it had a negative impact on customer satisfaction. Recall that in the business survey, the same question was asked and 69% of the businesses indicated that raised medians have a negative impact on customer satisfaction. Compared to the business survey results, a higher percentage of businesses than customers viewed the impact of raised medians on traffic congestion and safety to be negative.

Table E-6 in 0 shows a detailed summary of the responses by gender, type of customers, type of visit and type of corridors. As shown in Table E-6 in 0, a higher percentage of females, as opposed to males indicated that raised medians negatively affected all factors. A higher percentage of pass-by businesses' customers, as opposed to destination businesses' customers and a higher percentage of pass-by customers, as opposed to planned customers indicated that raised medians negatively affected all factors. Similarly, a higher percentage of customers that were surveyed on RIRM corridors as opposed to those surveyed on PIRM corridors indicated that raised medians negatively affected access to business and customer satisfaction, whereas a higher percentage of customers that were surveyed on PIRM corridors as opposed to those surveyed on RIRM indicated that raised medians negatively affected traffic congestion and traffic safety.

Customers were asked to rank following factors (i.e., on a scale of 1 to 6) that they considered when selecting the business ("1" being the most important).

- Travel Distance
- Hours of Operation
- Customer Service
- Product Quality
- Product Price
- Accessibility to Stores

Figure E-5 in 0 shows a summary of the response to this question. As shown in Figure E-5 in 0, only 7% of customers ranked accessibility to stores as their highest priority (1st) and 76% ranked it as 4th, 5th and 6th. Therefore, the majority of customers give accessibility to stores much lower importance than almost all other business factors. Despite the fact that installing raised medians limits the access to a business, customers do not rank this limitation as highly important, and thus, the change would have a minimally negative impact on the business. Table E-7 in 0 shows a detailed summary of the responses regarding accessibility to stores. A higher percentage of females (8%), as opposed to males (6%) ranked accessibility to stores as the most important factor. A higher percentage of pass-by businesses' customers (10%), as opposed to destination businesses' customers (4%) ranked accessibility to stores as the most important factor. The same percentage of planned and pass-by customers (7%) ranked accessibility to stores as the most important factor. A higher percentage of customers that were surveyed along PIRM corridors (9%), as opposed to customers that were surveyed along RIRM (5%) ranked accessibility to stores as the most important factor.

To study the impact of raised medians on visit frequency of customers, customers were asked about the impact of raised medians on their future visits to the business. Two slightly different questions were used along PIRM and RIRM corridors. Customers of businesses along a PIRM corridor were asked:

"Do you believe you will be more likely or less likely to visit this business if the raised median is not there on the main road?"

While customers on RIRM were asked:

"With the raised median, do you believe you are now more likely or less likely to visit this business or is it about the same?"

Figure E-6 in 0 summarizes the responses to this particular question by corridor types. Customers who were surveyed along PIRM corridors (i.e., corridors with raised medians) were asked about the effect on their frequency of visits if raised medians were not installed in the adjacent corridors. If the answer selected is "more likely," the median has a negative impact on the frequency of visit; on the contrary, if the answer choice is "less likely" or "stay about the same," then the raised median does not have a negative impact on the frequency of visits. As shown in Figure E-6 in 0, 12% of customers indicated that a raised median would make them less likely to visit a business, 29% indicated that they would be more likely and 59% indicated their visit frequency would stay about the same. These results indicated that the raised median has no negative impact on the visit frequency for the majority of customers (71%). As mentioned in the results of the business survey, 60% of business owners/managers indicated raised median had (or will have) negative impact on the average number of customers. In conclusion, the perception of the businesses is more negative than that of customers. In a follow-up question, customers were asked about their reasons for selecting the answer they chose. The results are presented in Table E-8 in 0. The majority of the customers (89%) indicated the reason they would be more likely to visit the business after removing raised median is that access to/from business would be more convenient. The participants that selected less likely indicated the reason is that the corridor would be more congested (54%), and getting to the business would be less safe (46%).

Customers who were surveyed along RIRM corridors (i.e., corridors where raised medians were recently installed) were asked about their frequency of visiting after the raised median was installed. If the answer is less likely, the median has a negative impact on the frequency of visit; on the contrary, if the answers are more likely or stay about the same, the raised median does not have a negative impact on the frequency of visits. As shown in Figure

E-6 in 0, 41% of responding customers indicated that a raised median would make them less likely to visit the business of interest, 7% indicated that a raised median would make them more likely to visit the business and 52% indicated their visit frequency would stay about the same. These results show that newly installed raised medians have had no negative impact on visit frequency for more than half of customers (59%). In a follow-up question, customers were asked about the reasons for their selection of less or more likely to visit a business. The results are presented in Table E-9 in 0. The majority of the customers selected more likely to visit (86%). Their reason for the increase in visit frequency is that the raised median would make it safer to access the business. About half of the customers (51%) indicated they would be less likely to visit a business. Their reasons is that the raised median would make it more difficult to access the business.

5.2.4 Chi-square Test Results of Customer Survey

To determine if there is an association between the business/customer/corridor attributes and the indicated impact of raised medians the Chi-Square test for independence was used. Specifically, it is used to answer the following hypotheses:

> **H_0:** Indicated response of impact of raised medians is independent of the gender of customers/type of business/type of visit/type of corridor
>
> **H_A:** Indicated response of impact of raised medians is not independent of the gender of customers/type of business/type of visit/type of corridor

Then the null hypothesis, H_0 is rejected, for 0.05 confidence level, if the p-value is less than 0.05. Table E-10 in 0 shows the results of the Chi-Square test.

With the exception of five cases (their p-values are shown in bold in Table E-10 in 0), all null hypotheses are rejected. Rejecting the null hypothesis implies that there is a statistically significant association. For example, there is a statistically significant association between the gender of customer and their indicated response regarding the impact of raised medians on traffic safety. In other words, male and female respondents indicated different opinions on the safety effect of raised medians. If the null hypothesis is not rejected, then there is no association. For example, there is no association between gender of customers and their indicated response regarding the impact of raised medians on customer satisfaction. In other words, males and females indicated similar experience on the customer satisfaction effect of raised medians.

The following summarizes key findings based on the survey results (summarized in Table E-6 in 0) and the Chi-Square test results.

- A higher percentage of female customers as opposed to male customers indicated that raised medians negatively affected safety.
- A higher percentage of pass-by businesses' customers as opposed to destination businesses' customers indicated that raised medians negatively affected all factors. Similarly, a higher percentage of pass-by customers as opposed to planned customers indicated that raised medians negatively affected all factors. This finding suggests that customers of pass-by businesses prefer easy access to the businesses.
- A higher percentage of customers surveyed along RIRM corridor as opposed to those along PIRM corridor indicated that raised medians negatively affected access to business and customer satisfaction. This finding suggests that raised medians initially is viewed as negative, but in the long run, the negative perception diminishes.

To determine if there is an association between the business/customers attributes and assigned ranks to accessibility the Chi-Square test for independence was used. The Chi-Square test results are presented in Table E-11 in 0 in terms of Chi-Square test statistic and p-value. All p-values are higher than 0.05, and thus, none of the null hypotheses is rejected. Therefore, there is no association between the assigned rank to accessibility and business/customers attributes.

5.3 Binary logit Model Results

A binary logit was developed where the response variable, Y, is the indicated response from businesses to the question regarding the impact of access management on their gross sales; the response was either negative impact or no negative impact. A total of eighteen explanatory variables were considered. These variables are related to businesses and corridors and their data were obtained from the survey, ReferenceUSA, Google Maps, U.S. Census and SCDOT's website. These factors were grouped into: (1) business characteristics, (2) roadway characteristics, and (3) socioeconomic characteristics. Based on the 68 observations, the model was estimated. A description of the response and explanatory variables are presented in Table E-12 in 0.

A systematic procedure for removing and adding variables was used to establish the final model. To test the effectiveness of the final model, the likelihood ratio test was used. As shown in Table 5-1, the unrestricted model log likelihood is -25.80 and the restricted model log likelihood is -47.01. The Chi-Square test statistic is 42.43 and the p-value is 0.000; the null hypothesis is rejected. This result indicates that two models are not statistically equivalent, and the explanatory variables are collectively significant in the binary logit model.

Table 5-1: Parameter Estimates and Partial Effect

Explanatory variable	Coefficient	Average marginal effect
COR_TYPE	3.15***	0.39
BUS_TYPE	2.25**	0.31
ON_PEAK	-2.11**	-0.30
MINOR	2.25***	0.30
LANE	-1.45***	-0.17
Log likelihood function	-25.80	
Restricted log likelihood	-47.01	
Chi squared	42.44	
Significance level	.00000	
Number of observations	68	

*** Significant at the 99% confidence level
** Significant at the 95% confidence level

As shown in Table 5-1, there are five statistically significant variables in the model: COR_TYPE, BUS_TYPE, ON_PEAK, MINOR, and LANE. Positive coefficients imply that as the explanatory variable value increases the probability of the business indicating that raised medians will have no negative impact will increase. On the contrary, negative coefficients imply that as the explanatory variable value increases, the probability of the business indicating that raised medians will have no impact decreases. As shown in Table 5-1, the coefficients of all statistically significant variables except for ON_PEAK and LANE are positive. For example, the coefficient associated with business type has a positive effect which indicates that destination businesses are more likely than pass-by businesses to indicate that raised medians will have no negative impact on their gross sales; whereas the coefficient associated with busiest times during peak hours has a negative effect, which indicates that businesses with the busiest times occurring during the peak hours are less likely than businesses with the busiest times occurring during the off-peak hours to indicate that raised medians will have no negative impact on their gross sales.

The marginal effect associated with corridor type indicates that if a business is located along the PIRM or RIRM corridor, then the probability that it will indicate no negative impact is 39% higher than a business located along the NRM corridor. The marginal effect associated with business type indicates that if a business is a destination business, then the probability that it will indicate no negative impact is 31% higher than a pass-by business. The marginal effect associated with busiest hours of a day indicates that if a business has the busiest times occurring during the peak hours, then the probability that it will indicate no negative impact is 30% lower than a business that has its busiest hours occurring during the off-peak hours. The marginal effect associated with having a driveway on a minor street indicates that if a business has a driveway available on a minor street, then the probability that it will indicate no negative impact is 30% higher than businesses that do not have a driveway available on a minor street. The marginal effect associated with the number of lanes implies that if the number of lanes along the corridor that a business is located increases by one, then the probability that it will indicate no negative impact decreases by 17%.

5.4 Safety Analysis Results

5.4.1 U.S. 17 (Mt Pleasant, SC)

Phases 2 and 3 of the U.S. 17 project were completed in 2013. Projects involved widening the road to three lanes in each direction, replacing depressed medians with raised medians and closing median breaks. In total, six median openings were closed in these projects (shown in Figure E-7 to Figure E-12 in 0). From Google Maps, ten new conflict points were identified and are presented in Figure E-7 to Figure E-12 in 0.

The number of crashes before and after the construction period is extracted from the crash database. Since the project was started in 2012 and completed in 2013, the number of crashes at new conflict points in 2011 (before the project) and 2014 were compared. Crash rates in ten new conflict points in 2011 and 2014 are presented in Table E-13 in 0.

To compare the means of crash rates in 2011 and 2014 and to investigate whether the crash rates increased between 2011 and 2014, the F-test was used to test for equality in variances. The results are presented in Table E-14 in 0. The p-value is less than 0.05. So, the null hypothesis is rejected, and thus, the variances are not equal

In the next step, a t-test with unequal variances was conducted. The results are presented in Table E-15 in 0. The p-value (0.29) is greater than 0.05 (i.e., significance level). Therefore, the null hypothesis cannot be rejected, and thus, it can be concluded that on average the crash rate in new conflict points before and after raised median installation are not significantly different. It can be concluded that the U.S. 17 corridor improvement project improved safety.

5.4.2 S.C. 327 (Florence, SC)

In the S.C. 327 project, a new median was provided, and a median opening was closed (presented in Figure E-13 in 0). From Google Maps, 2 new conflict points were determined (presented in Figure E-13 in 0).

Crash rates at the two new conflict points in 2012 and 2014 are presented in Table E-16 in 0. The sample size is too small to perform statistical analysis for this corridor. The data showed that the RMEV is lower after median installation. Based on this measure, it can be concluded that the S.C. 327 project improved safety in this corridor.

5.5 Summary

In this chapter, the perception of South Carolina businesses of raised medians was assessed, and the actual economic impact on these businesses was examined. A post-facto technique was used to analyze the actual sales volume of businesses obtained from ReferenceUSA to determine the actual economic changes after installing a raised median. The results indicate that the sales volume decrease of the affected businesses was similar to that of businesses in the control group. This finding suggests that the installed raised median was not the reason the affected businesses experienced a reduction in sales volume. The local and regional macroeconomics may have contributed to the decrease in sales volume of the affected businesses and their competitors.

Surveys were conducted to examine how businesses and customers perceive the impact of raised medians. From the survey results, the Chi-Square test was used. This test helped to establish whether or not there was a significant relationship between business perception, customer perception, and corridor attributes. Business survey results indicated that although more than half of businesses perceived raised medians to decrease the average number of customers per day, only 13% of businesses reported that accessibility is the most important factor considered by customers. When comparing the responses of businesses and customers, the results indicated that businesses perceive the impact of raised medians to be more negative than customers.

A binary logit model was formulated to determine which factors affect businesses perception of the impact of raised medians. The effect of statistically significant independent variables was provided in terms of marginal effects. The model results indicate that businesses that are located along the corridors with raised medians, destination businesses, businesses with driveway(s) on a minor street and businesses with high sales volume are associated with increased probability of indicating raised medians to have no negative impact on gross sales. Conversely, businesses with busiest hours occurring during the peak hours are associated with increased probability of indicating that raised medians have a negative impact on total sales.

In addition, a safety analysis was performed on selected corridors. The before-and-after analysis showed no negative impact on safety after an access management strategy was implemented in the studied corridors.

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CHAPTER 6 SUMMARY OF FINDINGS AND RECOMMENDATIONS

6.1 Summary of Findings

A previous SCDOT-sponsored research project evaluated the safety impacts of access management in SC. This study is a follow-up project that evaluated the operational and economic impacts of access management in SC. The operational analysis involved using traffic simulation to evaluate the effectiveness of a set of access management strategies on selected corridors with different roadway geometrics, land use, and business types in SC. The economic analysis involved conducting business and customer surveys to determine perception and used the post-facto technique to evaluate the actual economic impact. Findings from this research are summarized in the following subsections.

6.1.1 Summary of Findings from Online Survey

For each survey question, the number of total responses varied for each question because some DOTs did not complete the entire survey. The main findings from the online survey are as follows.

- The access management strategy most widely used in practice is driveway closure and separation along a corridor. A total of 81% of the survey participants indicated that they have implemented driveway closure/separation. The second most commonly used strategy is corner clearance (i.e., driveway restriction near the intersections); this strategy has been implemented by 75% of the survey participants.
- Ten state DOTs considered the economic impact in their access management standards. Seven state DOTs evaluated the economic impact of access management strategies.
- Fifteen DOTs indicated that they are considering economic impact in their future access management standards.
- When raised medians are selected for implementation, nineteen DOTs indicated that they prefer to provide a full median opening. Twenty-seven survey participants mentioned that opposition from business owners is the primary challenge in installing raised medians.

- Twenty-two DOTs identified the location of a driveway within the intersection influence area as the primary factor for restricting access (i.e., right-in only, right-out only, right-in/right out, left-in but no left out, etc.) from fully-open access. Twenty-three DOTs experienced improved operational condition after modifying driveways from fully-open to restricted access.
- Twenty-six DOTs identified opposition from business owners as the primary challenge in modifying access to a business.
- Nineteen DOTs indicated that they have consolidated driveways as an access management strategy, and seven have not. Fifteen participants noted that the mainline travel time decreased as a result of driveway consolidation.
- Twenty-four survey participants indicated that convincing business owners is the most challenging part of implementing shared traffic access.
- Twenty-three DOTs indicated that restricting driveway access in small isolated corner lots is difficult. The main reasons provided for choosing not to restrict access to corner lots are a) no alternative access is available, b) site geometry and topology, and c) cost. Twenty-two DOTs indicated it was a significant challenge to restrict driveway access due to the need to convince business owners about minimal impacts of driveway restriction on their businesses. The other challenge was the lack of corner clearance (i.e., providing sufficient distance from an intersection) policy for restricting access. One DOT indicated that it would have been helpful in their effort if they had a corner clearance (i.e., providing sufficient distance from an intersection) policy.

6.1.2 Summary of Findings from Phone Interview

The major findings from the phone interviews are as follows.

- Nine of the eighteen states that participated in the phone interview considered both safety and operational improvements in selecting an access management strategy. Seven states indicated that their primary concern is to improve safety when selecting an access management strategy.
- Among the eighteen states that responded, fifteen have faced lawsuits from business owners after implementing access management strategies.

- Five states stated that they seek to share expected benefits from published studies to convince business owners to support their proposed access management strategy.
- The access management strategies most commonly used to make spot improvements are:
    - Driveway consolidation
    - Addition of a median
    - Addition of a median opening
    - Median opening closure
- Among the seven states that have conducted economic impact studies, their findings are as follows.
    - Medians have no impact except on "impulse" (i.e., pass-by) businesses.
    - Access management benefitted business owners, (i.e., the number of customers that visited the affected businesses increased).
- Only three states have updated their access management policy/design guidelines based on the findings from their economic impact studies.

6.1.3 Summary of Findings from Operational Analysis

The operational improvements were found to be site-specific. This implies that in the future, separate simulation analysis needs to be conducted for any corridor to evaluate the operational impact of access management. However, some general trends were observed from the simulation results as follows.

- In the non-traversable median scenario, the mainline travel time increased for all study corridors when converted from TWLTL. For most of the corridors, the non-traversable median scenario increased mainline delay (up to 68%), stopped delay (up to 96%) and number of stops (up to 62%) after converting from TWLTL
- Among all four alternative scenarios, driveway consolidation decreased right-in[30] driveway travel time for eight corridors (with TWLTL or raised median) when converted from the condition where there was no driveway consolidation. For six corridors, the corner clearance scenario (i.e., providing sufficient distance from an intersection) decreased the right-in[30] driveway travel time more than the access restriction scenario

[30] Right-in movements from the immediate upstream intersection to the driveway

within the corner clearance distance. These results indicated that closing driveways in the intersection area of influence within the corner clearance distance reduced the average right-in[31] driveway travel time more than restricting the driveways to right-in/right-out only in the intersection influence area.

- Among the four different alternative scenarios (i.e., non-traversable median, driveway consolidation, access restriction, providing sufficient corner clearance distance from an intersection), the access restriction strategy (i.e., restricting driveways within the signalized intersection's influence area to right-in/right-out) yielded the lowest right-in[31] driveway delay in three corridors (with TWLTL or raised median) when converted from driveways with full access in the intersection influence area.
- The left-out[32] driveway travel time increased for both non-traversable median and access restriction scenarios. In both scenarios, the left-in[33] and left-out[32] are closed for specific driveways, so driveway entering/exiting traffic had to make a U-turn at the next signalized intersection which increased travel time. The driveway consolidation scenario improved the left-in[33] driveway travel time for nine of the corridors (4% to 54%). The corner clearance scenario (i.e., providing sufficient distance from an intersection) improved the left-in[33] driveway travel time for 6 corridors (9% to 56%).
- Driveway consolidation increased right-out[34] driveway travel time for six study corridors (with TWLTL or raised median), followed by the corner clearance scenario (i.e., providing sufficient distance from an intersection) where the average right-out[34] driveway travel time increased for five study corridors (with TWLTL or raised median).
- Non-traversable medians increased the travel time for all corridors, and the access restriction scenario (i.e., restricting access to right-in/right-out within the corner clearance distance) increased the travel time for left-out[32] traffic in eight corridors.
- For non-traversable median scenarios, the left-out[32] driveway delay and number of stops increased for eight out of nine study corridors. In the access restriction scenario, delay increased for six corridors and number of stops increased for seven out of eight study

[31] Right-in movements from the immediate upstream intersection to the driveway
[32] Left-out movements from the driveway to the immediate downstream intersection
[33] Left-in movements from the immediate upstream intersection to the driveway
[34] Right-out movements from the driveway to the immediate downstream intersection

corridors (with TWLTL or raised median) where the access restriction scenario was implemented.

- Spot improvement projects had no impact on the mainline traffic and driveway traffic operations on driveways where improvements were not made.

6.1.4 Summary of Findings from Economic Analysis

The major findings from the economic analysis are as follows.

- The results of the post-facto analysis indicated that, despite a three-year decrease in affected business sales volume, the control group without a raised median experienced similar losses. These results suggest that the installed raised median was not the cause of the affected businesses' decrease in sales volume.

- 27% of customers indicated that raised medians have an adverse effect on customer satisfaction while 69% of businesses indicated that raised medians have an adverse effect on customer satisfaction. These results suggest that businesses perceive the impact of raised medians to be more negative than customers.

- 13% of businesses identified accessibility to businesses as their customers' first priority, whereas 7% of customer ranked accessibility to businesses as the 1st priority. These results indicate that businesses perceive customers to value accessibility more than customers actually do.

- Although 60% of businesses indicated that raised medians have an adverse effect on the average number of customers per day, only 13% of businesses indicated that accessibility is the most important factor considered by customers. Although more than half of the businesses indicated that the left-turn restriction from a driveway had a negative effect on their businesses, only a small portion of them identified accessibility to businesses as their customers' topmost priority.

- Although 89% and 80% of pass-by businesses indicated that raised medians had (or will have) an adverse effect on the average number of customers and gross sales, respectively, only 17% of them identified accessibility to business as the most important factor considered by their customers. These results suggest that although the majority of pass-by businesses indicated that the left-turn restriction had an adverse effect on their businesses, the majority of pass-by business owners did not indicate accessibility as the determining factor for customers' visit.

- 52% and 60% of businesses indicated that raised medians have a negative impact on the gross sales and the average number of customers per day, respectively. The results of the post-facto analysis showed no negative impact on businesses in selected corridors due to the raised medians. These results suggest that the perceived negative impact by businesses is not consistent with what actually occurred after converting TWLTL to raised medians.
- For corridors where raised medians were installed more than two years ago, a majority (89%) of the customers indicated they would be more likely to visit a business after raised medians are removed; they cited more convenient access as their motivation. For corridors where raised medians were recently installed, about half (51%) of the customers indicated a decreased likelihood to visit a business after installation of a raised median; they cited more difficult access to the business as the reason.
- The Chi-Square test results showed that there is a significant association between the business/customer/corridor attributes (i.e., business types, business size, busiest hours of the day, the gender of customers, type of customer's visit and corridor type) and the indicated impacts of raised medians on gross sales. The indicated impacts of raised medians (based on the Chi-Square test results) are listed below.
    - Small-sized businesses, pass-by businesses, and business located along corridors without a raised median indicated that the impact of raised medians was (or will be) more negative compared to large-sized businesses, destination businesses and business located along corridors with a raised median.
    - Customers surveyed from both pass-by businesses and businesses along the corridors with recently installed raised medians, indicated that the impact of raised medians was (or will be) more negative compared to destination business and businesses located along corridors with previously installed raised medians.
- The results of binary logit model indicated that:

- Destination businesses are more likely to indicate that raised medians will have no negative impact on their gross sales than pass-by businesses.
- Businesses with a driveway on a minor street are more likely to indicate that raised medians will have no negative impact on their gross sales than businesses that do not have a driveway available on a minor street.
- Businesses located along the corridors with raised medians are more likely to indicate that raised medians have no negative impact on their gross sales than businesses located along the corridors without raised medians.
- Businesses with the busiest times occurring during the peak hours (i.e., 8-10 AM and 4-6 PM) are less likely to indicate that raised medians will have no negative impact on their gross sales than businesses with the busiest times occurring during the off-peak hours.
- Business located along the corridors with a greater number of lanes are less likely to indicate that raised medians will have no negative impact on their gross sales than businesses located along the corridors with fewer lanes.

6.1.5 Summary of Findings from Safety Analysis

The major findings from the safety analysis are:

- The installed raised median on US-17 (in phases two and three) effectively removed six median openings (i.e., conflict points). Analysis of crash rates at new conflict points (where vehicles need to make a U-turn) showed no difference between the before and after crash rates.
- The access management strategies implemented on SC-327 involved adding a raised median and removing one median opening. Analysis of crash rates at new conflict points showed no difference between the before and after crash rates.

6.2 Relationship of Operational and Economic Impacts with Safety Impacts of Access Management

Table 6-1 depicts the operational, safety and economic impacts of access management alternatives for SC corridors.

Table 6-1: SC Access Management Project Impacts

	Operational	**Safety**	**Economic**
Non-Traversable Median	• Increased mainline travel time - all corridors up to 18% • Increased mainline stopped delay up to 96% • Increased left-in[35] and left-out[36] driveway travel time for all corridors	• Caused 0 crashes/ driveway for grass median • Caused 0.14 crashes/ driveways for raised median	Despite the three year decrease in affected business sales volume, negative economic impact is insignificant as similar losses were observed in control group unaffected by median installation
Driveway Consolidation	• Reduced mainline travel time up to 4.5% • Decreased right-in[37] and left-in[35] driveway travel time	Reduced crash with increasing driveway spacing	
Corner Clearance	• Decreased the left-in[35] and right-in[37] driveway travel time • Increased the right-out[38] and left-out[36] driveway travel time in some cases	Increased crash frequency within the corner clearance distance with the increased AADT and number of driveways (within corner clearance)	
Right-In/Right-Out Only Driveway	• Increased right-in[37] driveway travel time for most corridors • Increased the left-in[35] driveway travel time for all corridors	Caused 0.16 crash/driveway for unchannelized right-in/right-out driveway compared to 0.36 crashes/driveway with full access	

[35] Left-in movements from the immediate upstream intersection to the driveway
[36] Left-out movements from the driveway to the immediate downstream intersection
[37] Right-in movements from the immediate upstream intersection to the driveway
[38] Right-out movements from the driveway to the immediate downstream intersection

6.3 Recommended Modifications to SCDOT ARMS

The findings and recommendations reported in the SCDOT sponsored project completed earlier titled "Support for the Development and Implementation of an Access Management Program through Research and Analysis of Collision Data" focused primarily on safety [9]. This project [9] did not focus on operational and economic impact assessments, thus there remains a gap in the ARMS Manual in regard to operational and economic considerations addressed in this research. Such considerations will not only make roads safer, but also improve traffic flow. With improved traffic flow and safety, the surrounding businesses will stand to benefit in the long run as reported in previous studies.

A limited number of states have conducted research on economic impacts of access management strategies. Over the years, the results have shown that the business owners may initially have a negative perception toward access management. However, after implementation of access management measures, their views are often reversed. Many businesses have experienced that the number of customers per day and total sales increased after the access management implementation. However, objections from business owners continue to be a point of contention in many roadwork projects involving access management. Some states, having conducted the research, have already included operational and economic provisions in their access management manuals. The Texas DOT access management manual includes a comprehensive economic impact section, while the Kansas DOT access management manual provides provisions in regard to operational and economic impact throughout. The following recommendations are developed for consideration by the SCDOT in the future versions of the ARMS Manual, based on operational and economic analysis conducted in this study, and previous SCDOT safety study [9] on access management.

Recommendations for Access Management Alternatives [34]**:**

- **Non-traversable Median:** In all study corridors, a non-traversable raised median resulted in less efficient travel for both mainline traffic and driveway entering and exiting traffic compared to the TWLTL. However, from a safety perspective, crash rates for non-traversable medians (i.e., zero crashes/driveway for grass median and 0.14 crashes/driveways for raised median) were found to be lower than that of TWLTL (i.e., 0.36 crashes/driveways) [9]. This finding suggests non-traversable raised medians yield positive safety benefits and have a negative operational impact. This study found that raised medians did not have a negative economic impact on businesses in SC. The local/regional economy was found to be the primary cause for the decrease in sales volume at the affected businesses.

- **Driveway Consolidation:** It was found in the operational analysis that driveway consolidation improved the mainline traffic flow. Driveway consolidation also has safety benefits [9]. For all high-turnover businesses (i.e., fast food or similar businesses), driveway consolidation should be implemented following the SCDOT ARMS criteria.
- **Right-In/Right-Out Only Driveways:** In [9], right-in/right-out driveways were recommended along major roadways, and full access driveways were recommended on side streets for safety. [9]found that right-in/right-out driveways, implemented only within the signalized intersection's influence area (i.e., corner clearance), were producing less stopped delays for mainline traffic when converted from driveways with full access. To maximize operational efficiency while improving safety, it is suggested to use channelization in the driveways, within the signalized intersection's influence area, to restrict left-turns into or out of the driveway. This particular strategy will not only improve safety but also reduce delay for mainline traffic.
- **Providing Sufficient Corner Clearance from an Intersection:** The corner clearance (i.e., providing sufficient distance from an intersection according to SCDOT ARMS manual) and driveway consolidation scenarios were effective in reducing driveway entering and exiting travel time. Safety analysis revealed that these two alternatives also reduced crash rates [9].
- **Spot Improvement:** The spot improvement projects do not affect the operational condition of the mainline traffic but can help reduce access related crashes. SCDOT should consider implementing small-scale spot improvements for driveways where safety improvements are needed.
- **Economic Impact:** Although access management strategies (i.e., both corridor-wide and spot improvement projects) restrict access to businesses, a properly designed access control provides safe and efficient roadway operation as well as effective access to adjacent businesses. In the long run, businesses reap the advantages of access management due to better traffic safety and traffic flow along the corridors.

Table 6-2: Proposed Additions to the SCDOT ARMS Manual

Access Management Alternatives	***ARMS provisions (Chapter, Section, Page)***	***Suggested Provisions to be Added to ARMS Manual***		
		Operational Impact (this study)	***Safety Impact*** [9]	***Economic Impact (this study)***
Non-traversable Median	• Defines median of a divided highway as the provider of a safer, more efficient traffic movement (Ch. 2, Sec. 2D-11, pg. 18) • Lists median crossover requirements and design criteria (Ch. 3, Sec. 3D, pg. 32-33)	• Deteriorates operational condition for mainline traffic • Deteriorates left-in[39]/left-out[40] driveway traffic operational condition. An earlier study [32] also found that RTUT vehicles, at signalized intersections, experienced more delay than DLT	Improves the safety condition with respect to TWLTL	Does not negatively impact the affected businesses
Driveway Consolidation	• Suggests driveway spacing based on AADT and driveway traffic where any exception can be allowed (Ch. 3, Sec. 3C-1, Pg. 27) • Encourages shared driveways, and states where SCDOT may require shared driveway implementation (Ch. 3, Sec. 3C-6, Pg. 31)	• Does not negatively affect mainline traffic travel time • Decreases driveway entering travel time	Improves the safety condition with increasing driveway spacing	Was not evaluated in this study
Corner Clearance (i.e., providing sufficient distance from an intersection)	• Suggests corner clearance based on AADT and driveway traffic, and where any exception can be allowed (Ch. 3, Sec. 3C-2, Figure 3-9, Pg. 29) • Describes how driveways should adhere to the corner clearance requirements in cases where left-turn lanes exist, and intersection has large turn radius (Ch. 3, Sec. 3C-2, Pg. 28)	• Decreases the driveway entering (left-in[39] and right-in[41]) travel time • Increases the driveway exiting (left-out[40] and right-out[42]) travel time	Improves safety condition if no driveways are located within the corner clearance distance	Was not evaluated in this study
Right-in/right-out only Driveway	• Describes right-in/right-out driveway design criteria (Ch. 3, Sec. 3B-7, Pg. 25) • Suggests corner clearance distance for right-in/right-out driveways (Ch. 3, Sec. 3C-2, Figure 3-9, Pg. 29)	• Increases the driveway entering (left-in[39] and right-in[41]) travel time • Increases travel time for left-out[40] driveway traffic	Improves safety condition compared to driveways with full access	Does not negatively impact the affected businesses

[39] Left-in movements from the immediate upstream intersection to the driveway
[40] Left-out movements from the driveway to the immediate downstream intersection
[41] Right-in movements from the immediate upstream intersection to the driveway
[42] Right-out movements from the driveway to the immediate downstream intersection

Proposed additional provisions for the SCDOT ARMS Manual are provided in Table 6 2.

6.4 Considerations for Existing SCDOT Highway Design Manual

The purpose of the South Carolina Highway Design Manual [35] is to ensure uniform design practices for roadway construction projects in SC. The manual discusses nine different design elements, which include basic design controls, such as roadway safety, horizontal and vertical alignment, sight distance, cross section elements, intersections, interchanges, and special design elements (i.e., accessibility for disabled individuals, noise control). The sections which focus on access management, median and channelization are listed below:

- The section titled 'Basic Design Controls' defines access management and general intersection related considerations (i.e., intersection radii, sight distance, limited access facilities, and median opening) for determining access control.
- The 'Cross Section Elements' section discusses functions, types and selection criteria of medians. Among three types of medians (i.e., flush, raised and depressed medians), the raised median is identified as a better strategy to manage access.
- The 'Intersection' section discusses the different types of channelization that can be applied to right-in/right-out only driveways.

The following recommendations are developed for consideration by the SCDOT in future versions of the Highway Design Manual.

- To allow U-turns at signalized intersections, the minimum turning radius for selected design vehicles following the South Carolina Highway Design Manual should be provided. U-turns can be allowed at mid-block. Florida DOT Median Handbook evaluated the mid-block U-turn, which can serve as a reference for future implementation [36].
- The South Carolina Highway Design Manual should specify the location for U-turn for RTUT traffic. In this report, RTUT movements were allowed for both mainline and driveway traffic at the nearest feasible signalized intersection, which was determined using the suggested offset distances provided by Lu et al. [19].

- In case of insufficient right-of-way for U-turn at a mid-block or intersection, the bowtie intersection, quadrant roadway, continuous flow intersection, superstreet or Jughandle can be considered [37].

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APPENDIX A LITERATURE REVIEW

A. 1 Review of National Guidelines and Resources

Presented below is the relevant information from the reviewed national guidelines and resources as it applies to the four access management strategies, driveway consolidation, providing sufficient corner clearance, from an intersection access restriction and non-traversable median. It should be noted that while these documents have much to say in many different areas of access management design principles, only those relevant to this research are presented.

TRB Access Management Manual

The TRB Manual [1] titled 'Access Management Manual 2014' is a synthesis of policy, warrant, and design information from national studies, peer-reviewed research, and state practices. The ways in which it speaks to the strategies of consideration in this project are presented in this section.

1. Access Spacing: Average driveway entry speeds are typically between 8 and 13 mph, creating high speed differentials (between driveway turning vehicles and mainline through traffic) which occur in advance of the location where a turning maneuver is executed. Proper spacing of access points is critical for safe and efficient operation of an arterial. Poor spacing, design, and location of driveways can reduce average speeds by up to 5 to 10 mph. For a 45-mph roadway, the spacing can be suggested based on nine considerations, which are: (a) independent access connections – defining spacing based on the upstream and downstream functional distances from adjacent access points – this tends to lead to long and typically unreasonable access spacing (1,045 ft.); (b) upstream functional distance – defines the spacing by the upstream functional distance only (280-410 ft. – depending on functional distance calculation method); (c) turn lane design – defines the spacing such that it is larger than the right-turn auxiliary lane length so that there is no overlap between driveways and the lane (369 ft.); (d) safety; (e) stopping sight distance (SSD) – spaces access at distances equal to or longer than the SSD (360 ft.); (f) intersection sight distance – bases the spacing on the distance needed to provide a driver waiting at an access an opportunity to enter or cross the major roadway (430-500 ft.); (g) decision sight distance – spaces access in terms of the sight distance from the perspective of the driver traveling on the roadway (395-960 ft. – depending on maneuver); (h) right-turn conflict overlap – spaces access such that a driver on the mainline does not have to monitor more than one right-turn ingress movement at a time (350 ft.); and (i) egress capacity – spaces access such that the egress capacity of driveways is maximized (870 ft.). Based on the TRB manual, depending on the approach employed, recommended unsignalized access spacing (for a 45-mph roadway) ranges from 280 to 1,045 ft.

2. Corner Clearance: Driveways should be restricted from the intersection functional area and the other driveways' influence areas. When an access connection within the functional distance cannot be avoided, movements should be restricted to right-in/right-out only. Having adequate corner clearance improves signal capacity and safety. For a 40-50 mph design speed, the recommended minimum upstream and downstream corner clearance is 410-585 ft. and 360 ft. respectively.
3. Non-traversable Medians: Non-traversable medians are recommended for implementation on major roadways in new locations, existing major roadways with current or projected ADT in excess of 24,000 to 28,000 vehicles, undivided roadways and roadways with a TWLTL on which operational or safety problems are evident, and generally on roadways of four or more lanes. Non-traversable medians drastically reduce conflict points, leading to improved safety. The TRB Manual [1] strongly recommends using directional median openings as opposed to full median openings, as they further reduce conflict points and reduce crashes. The distance needed between signals to accommodate directional median openings is determined by the sum of length of turn bays at the signals, turn bays at the directional openings, and minimum width of full median width. The TRB Manual [1] also presents median separator widths needed for U-turn movements. For a passenger car (P) on any four-lane road with a dedicated left-turn lane, a median width of 30 ft. is required. On any six-lane road with a dedicated left-turn lane, a median width of 18 ft. is required.

NCHRP Report 420 – Impacts of Access Management Techniques

NCHRP Report 420 [38] is a comprehensive review of the impacts of a wide range of strategies. In [38] three policy-related techniques and 21 design-related strategies were identified. Of these strategies, establishing spacing for unsignalized access, establishing corner clearance criteria, and replacing TWLTLs with non-traversable medians, and installing U-turns as an alternative to DLT were all ranked in the highest category of importance to access management. Consolidating driveways was rated as medium importance. The key conclusions from [38] as they relate to the strategies of consideration in this report are presented below.

1. Access Spacing: One general finding of the report was that when the number of access points is increased, there are higher accident rates. Operationally, the report references the 1994 HCM which shows a reduction of 2.5 mph in free-flow speed with every additional 10 access points per mile. Another referenced study in the report showed a speed reduction of 0.15 mph per access point.

2. Non-traversable Medians: The safety finding is that raised medians have resulted in reduced crash rates when compared with TWLTL and Undivided highways, and replacing direct left turns with U-turn movements can result in a 20 % accident reduction rate. In [38], the report notes that most operational analysis have focused on TWLTLs. Various studies cited in [38] show that TWLTLs generally result in lower delays than raised medians, however, the differences are not statistically significant. The travel time impacts of providing U-turns as DLT alternatives were studied and presented, where it is estimated that arterial traffic in excess of 375 to 500 vphpl on a four-lane facility, results in delays of direct left turning traffic exceed those of the alternative RTUT traffic. In general, the report claims that RTUT movements "can provide comparable, if not shorter, travel times than direct left turns from driveways under heavy volume conditions when the diversion distances are generally less than 0.5 miles."

NCHRP Report 524 – Safety of U-Turns at Unsignalized Median Openings

NCHRP Report 524 [39] concluded that there was "no indication that U-turns at unsignalized median openings constitute a major safety concern." Additionally, "there was no indication that safety problems result from occasional use of median opening spacing as short as 300 to 500 ft."

NCHRP Report 348 – Access Management Guidelines for Activity Centers

NCHRP 348 [40] states that "driveway access should be located opposite other access" (i.e., access for the opposite direction traffic), and placed beyond normal backups of traffic from signalized intersections. It is recommended closing/relocating driveways within 100 ft. from a signalized driveway. In [40] the general guidelines presented for unsignalized access spacing is 300-550 ft. for 45 mph roadways, and 300-800 ft. on roadways with ADT of 1,500 or more. [40] also recommends median opening spacing of 670 ft. for 45 mph roadways.

TRC 456 – Driveway and Street Intersection Spacing

Transportation Research Circular (TRC) 456 [41] presents general considerations for establishing spacing criteria. These considerations are very similar to the nine presented in the TRB Access Management Manual, which were discussed earlier in this report.

Summary of National Guidelines and Resources

There is a general consensus that increased spacing of driveways (and corner clearances) is safer and more operationally efficient. The suggested values for spacing vary by source and by the approach used to determine them. While national guidelines do include design guidelines for channelization of driveways, they do not include criteria for restricting full driveway access of right-in/right-out.

A. 2 Review of State Practices

The purpose of this subsection of the literature review is to provide warrants, recommendations, and guidelines currently adopted by state transportation agencies relating to the access management strategies studied in this report. An overview of these findings is presented in the sub-sections that follow, with comparison tables included at the end of the section. This information is relevant in determining if/where there is a consensus about warranting and designing certain access management strategies, and in determining values to use and test in the simulation analysis of this research.

Non-Traversable Median Recommendations

Connecticut [42] warrants raised medians on roadways where design speeds are 50 mph or less.

Florida [36] requires all roadways over 40 mph in design speed have some restrictive median treatments. All 7-lane roadway sections have the highest priority for retrofit, while all 5 lane sections and facilities with over 28,000 in daily traffic have high priority for retrofit.

Georgia [43] recommends raised medians on multilane roadways with design speed greater than 45 mph and on multilane roadways with 3 or more lanes in each direction. Georgia also recommends spot improvements of raised medians at intersections with “18,000 base year ADT and 24,000 design year ADT, an accident rate greater than the state average, and excessive queue lengths.”

Idaho [44] recommends raised medians “on all new multilane state highways, modernization of multilane state highways of posted speeds of 45 mph or greater, all undivided state highways where annual collision rate is greater than statewide annual average collision rate for similar roadways, and state highways when ADT exceeds 28,000 vehicles per day both directions and on all multi-lane state highways undergoing resurfacing, restoration, and/or rehabilitation.”

Kansas [45] provides that “raised medians are usually used in developed locations and should only be used when speeds are equal to or less than 45 mph” and when volumes are above 20,000 AADT on 5-lane roadways.

Kentucky [46] recommends raised medians on “all new multilane arterials and existing roads where ADT, access density, and/or turning volumes exceed thresholds for TWLTL’s.” Kentucky’s guidelines for TWLTLs in Urban/suburban multi-lane roadways are as follows:

- Projected ADT < 24,000

- 10 accesses/mi < Access Density < 85 accesses/mi
- Left-turn volume < 100 vph

Kentucky also recommends raised medians on any (2-lane and Multilane) Urban Principal Arterial with speeds higher than 45 mph, and speeds less than 45 mph but volume greater than 10,000; on Multilane Urban Principal Arterials; on any (2-lane and Multilane) Urban Minor Arterial with speeds greater than 45 mph and volume greater than 10,000; and on Multilane Urban Minor Arterials with speeds greater than 45 mph or with speeds less than 45 mph but volume greater than 5,000.

Maine [47] and Michigan [48] warrant raised medians on multilane roadways with AADT of 25,000 or greater.

Mississippi [49] has separate warrants raised medians in a spot improvement type implementation and in a corridor-wide implementation. Roadways with speed limit greater than 40 mph and ADT greater 30,000 should have median along length of corridor. Roadways with speed limits less than 40, and ADT less than 30,000 should have spot medians to improve safety where deemed necessary.

Missouri [50] recommends raised medians, in general, "where current and projected volume is greater than 28,000 AADT. They are especially recommended in corridors where traffic volume is high, density of commercial driveways is high (over 24/mile in both directions), and other access management strategies (i.e., driveway consolidation and corner clearance) are not practical. Raised medians should be used on arterial facilities with 3 or more through traffic lanes in each direction."

New York [51] recommends non-traversable medians where high traffic volume, sight restrictions, rates of left-turning traffic, and traffic speeds indicate that a problem may be expected due to the left turning movements.

Oregon [52] recommends raised medians on all new, multilane expressways on new alignments; all other existing urban expressways should consider construction of non-traversable median when projects are developed along these highways.

Pennsylvania [53] provides general criteria for raised medians on roadways of "a history of crash rates caused by conflicting turning movements, high average daily traffic, and unacceptable LOS along the corridor and at intersections."

Texas [54] recommends raised medians on roadways when ADT volumes are "greater than 20,000 vpd, and the demand for mid-block turns is high."

Washington [55] recommends "considering restrictive medians on multilane limited access highways and multilane managed access highways when design hourly volume (DHV) is over 2000 vph."

The results from the state of practice review of state transportation agencies for restrictive median recommendations (by design speed, number of lanes, traffic volume, accident rate, access density, and left-turn volume where applicable) are shown on the following page in Table A-1. The most common warrant variable cited by states is traffic volume. Of the 13 states which had raised median warrants, 12 include a traffic volume threshold above which non-traversable medians should be considered. ADT volumes cited range from 20,000 to 30,000 vpd, and one state recommends using design hourly volume (DHV) of 2,000 vph. The other common warrant variables are design speed and the number of lanes. Typically, states recommend implementing raised medians on roadways with design speeds ≥45 mph, however a few states recommend raised medians on roadways with design speeds less than this value. For states that referenced the type of facility, all recommended raised medians on multilane facilities.

Table A-1: Comparison Summary of State Agency Non-Traversable Median Recommendations

State	Design Speed	Number of Lanes (in one direction)	Traffic Volume	Accident Rate	Access Density	Left-Turn Volume
Connecticut	< 50 mph	--------	--------	--------	--------	--------
Florida	> 40 mph	2 & 3 lanes	ADT > 28,000 vpd	--------	--------	--------
Georgia	> 45 mph	≥ 3 lanes	ADT ≥ 24,000 vpd	> state average	--------	--------
Idaho	> 45 mph	≥ 2 lanes	ADT ≥ 28,000 vpd	> state average	--------	--------
Kansas	≤ 45 mph	--------	ADT > 20,000 vpd	--------	--------	--------
Kentucky	> 45 mph	≥ 2 lanes	ADT > 24,000 vpd	--------	> 85 access/mile	> 100 vph
Maine	--------	--------	ADT > 25,000 vpd	--------	--------	--------
Michigan	--------	--------	ADT > 25,000 vpd	--------	--------	--------
Mississippi	> 40 mph	--------	ADT > 30,000 vpd	--------	--------	--------
Missouri	--------	≥ 3 lanes	ADT > 28,000 vpd	--------	> 24 access/mile (in both directions)	--------
Texas	--------	--------	ADT > 20,000 vpd	--------	--------	--------
Washington	--------	--------	DHV > 2,000 vph	--------	--------	--------

Non-traversable Median Opening Spacing Guidelines

Many states provide median opening spacing guidelines according to different roadway functional classes, speed limits, and degree of urban development. For the sake of comparison and brevity, only those guidelines relevant to the corridors studied in this research are presented: four-six lane urban and/or suburban minor and/or principal arterials that are fully developed and have a 45-mph posted speed. Thus, unless otherwise noted, the spacing presented is the spacing the state provides for roadways with those characteristics. Full median crossovers/openings are those openings that permit all movements, whereas directional median crossovers/openings are those that only allow left-in/U-turns. Where the state has not specified between full and directional median opening, full median opening has been assumed.

Alabama [56], Florida [36], Kansas [45], Missouri [50], and Montana [57] recommend a full median crossover spacing of 1,320 ft. and a directional median crossover spacing of 660 ft.

Connecticut [42] provides median openings at all intersections and recommends full median crossover spacing be between 1,320 and 2,640 ft.

Delaware [58] recommends full median crossover spacing of 1,000 to 1,500 ft.

Georgia [43] recommends a preferred full median crossover spacing of 2,000 ft. and a minimum spacing of 1,000 ft.

Idaho [44] recommends "full median crossovers at all signalized intersections, locations meeting the criteria for a signal warrant, locations anticipated to meet future traffic signal considerations, locations where a median opening would pose no significant reduction in safety or operational efficiency." Openings are subject to Idaho DOT approach spacing guidelines.

Illinois [59] recommends full median crossover spacing be between 660 ft. and 1,320 ft.

Indiana [60] recommends that new median openings be spaced at least 400 ft. from an existing crossover given that it would improve the safety of the corridor.

Kentucky [46] recommends a full median crossover spacing of 2,400 ft. and a directional median crossover spacing of 1,200 ft. "Mid-block median openings (used for U-turns only) may be located 300 feet from an intersection at which left-turns are restricted if the following conditions are met: adequate sight distance, adequate space for accommodating U-turn design vehicle, adequate space for incorporation of "left-turn" auxiliary lane (including taper and storage), and there is no potential for use by drivers desiring to turn left from nearby driveways"

Louisiana [61] recommends U-turn median openings for passenger cars be spaced at 1,320 ft., partial median crossovers be spaced at 2,640 ft., and full median crossovers be allowed only if traffic signal spacing requirements are met.

Maine [47] recommends full median openings at all public roads and major traffic generators and/or at a spacing of 100 feet plus the left-turn lane length.

Maryland [62] recommends full median opening spacing be 750 ft. on urban arterials (densely developed with posted speed limits ≤40 mph and 1,500 ft. on suburban arterials.

Michigan [48] recommends that as long as medians are 30 ft. or more in width, median crossovers may be spaced at 660 ft. apart, and adjusted 100 ft. either way according to design needs.

Mississippi [49] recommends full and directional median crossovers be spaced 1,760 ft. apart.

New York [51] recommends that "openings be provided only at major cross streets and places that serve large traffic generators or emergency vehicles, and to avoid opening the median for low volume (one-way, design-hour volume of 100 vph or less) intersecting streets and left movements from the arterial."

North Carolina [63] states that median crossover spacing is "largely dependent upon the need for adequate storage for left turning and U-turn vehicles at intersections. A crossover shall not be placed where it interferes with storage requirements for existing intersections. All movement crossovers shall not be spaced any closer than 1,200 ft. apart. Where this spacing requirement is not met and there is a defined need for left-turn access, then a directional crossover will be considered."

Oregon [64] recommends that for major arterials, the full median opening spacing be 1,320 ft. and that for minor arterials this spacing be 330 ft.

Pennsylvania [53] recommends that the "spacing of median breaks shall be in accordance with the minimum driveway spacing, traffic signal spacing and corner clearance requirements."

South Carolina [18] spacing for full median crossovers is 500 ft.

South Dakota [65] recommends that both full and directional median openings be spaced at 1,320 ft. apart.

Texas [66] recommends providing median openings at all public roads and at major traffic generators (i.e., industrial sites or shopping centers). Additional openings should be provided so as not to surpass a maximum of 2,640 ft. Openings should be located where adequate sight distance is

Table A-2: Comparison Summary of State Agency Median Opening Spacing Guidelines

State	Full Median Openings (ft.)	Directional Median Openings (ft.)	For U-Turns Only (ft.)
Alabama	1,320	660	--------
Connecticut	1,320 - 2,640	--------	--------
Delaware	1,000 - 1,500	--------	--------
Florida	1,320	660	--------
Georgia	2,000 (preferred) | 1,000 (minimum)	--------	--------
Idaho	At all signalized intersections	--------	--------
Illinois	660 - 1,320	--------	--------
Indiana	400	--------	--------
Kansas	1,320	660	--------
Kentucky	2,400	1,200	300 (from an intersection)
Louisiana	If signal spacing requirements met	2,640	1,320
Maine	100 + left-turn lane length (and at public roads and major traffic generators)	--------	--------
Maryland	750 (urban) | 1,500 (suburban)	--------	--------
Michigan	660 (± 100)	--------	--------
Mississippi	1,760	1,760	--------
Missouri	1,320	660	--------
Montana	1,320	660	--------
New York	At major cross-streets, and large traffic generators (≥100 vph)	--------	--------
North Carolina	1,200 (minimum)	When 1,200 not available	--------
Oregon	1,320 (major arterials) | 330 (minor arterials)	--------	--------
Pennsylvania	According to minimum driveway spacing, signal, corner clearance spacing	--------	--------
South Carolina	500	--------	--------
South Dakota	1,320	1,320	--------
Texas	All public roads and major traffic generators | 2,640 (maximum)	--------	--------
Utah	Outside of functional area of interchange, intersection	--------	--------
Virginia	1,050 (major arterials) | 660 (minor arterials)	--------	--------
Washington	1,320	--------	1,000

available and where median is sufficiently wide to permit an official design vehicle to turn between inner freeway lanes.

Utah [33] does not allow median openings "within the functional area of an existing or planned interchange, signalized intersection, or major unsignalized intersection."

Virginia [34] provides different spacing regulations from different types of intersections/access. For principal and minor arterials, the "spacing from unsignalized intersections and full median crossovers to signalized or unsignalized intersections and full median crossovers is 1,050 ft. and 660 ft. respectively."

Washington [20] recommends that median opening used only for U-turns be spaced at 1,000 ft., with a minimum acceptable spacing of 300 ft. plus, the acceleration lane length from a stop. For full median openings, the Washington guideline is 1,320 ft.

A summary comparison table of the findings from the review of state practices is shown in Table A-2. While numbers vary for each state, a common recommended spacing for full and directional median openings on the mainline is 1,320 ft. and 660 ft. respectively.

Driveway Spacing Guidelines

Similar to median opening spacing guidelines, many states provide driveway access spacing in terms of speed. Again, for the sake of comparability and brevity, only spacing for the 45-mph posted speed are presented here, with other qualifiers noted for each state as they pertain.

Alabama [56] specifies access spacing according to the presence of a median. Without a median, directional access can be spaced 440 ft. apart and full access 660 ft. With a median, directional access is to be spaced 440 ft. apart and full access 1,320 ft. apart. Shared or individual direct connections to out-parcels may be provided if "twice the normal spacing requirements are met." Multiple Driveways will only be considered on parcels with frontage road greater than 660 ft. If 3 driveways are desired on one parcel, there must be frontage in excess of 1,980 ft.

Colorado [67] permits one access per parcel "if reasonable access cannot be obtained from a local street or road system. Additional right-turn only access is allowed where acceleration and deceleration lanes can be provided." This results in a recommended spacing of 325 ft.

Connecticut [42] permits parcels with frontage between 50 and 100 ft. to have 2 entrances if one-third of total frontage is used to separate driveways.

Delaware [58], Indiana [60], and Utah [68] provide an ideal driveway spacing of 350 ft.

Florida [69] provides a driveway spacing of 245 ft.

Georgia [70] recommends a spacing of 230 feet for access without a right-turn lane and 369 feet for access with a right turn lane.

Idaho [44] recommends a driveway spacing of 150 ft.

Illinois [59] allows two driveways for an average commercial property. “Between entrances into shopping centers and similar developments that generate high traffic volumes, a minimum of 440 ft., and preferably 660 ft. is required.”

Iowa [71] recommends a spacing of 300 to 600 ft.

Kansas [45] recommends a driveway spacing of 300 ft.

Kentucky [46] recommends a commercial, industrial, recreational driveway spacing of 1,200 ft.

Louisiana [72] provides for a spacing of 550 ft., however the spacing may be reduced by one-half if a non-traversable median exists within 200 ft. of both sides of the access and connection and a right-in/right-out access connection is installed.

Maine [73] recommends a driveway spacing of 265 ft.

Maryland [62] requires “a minimum 20’ tangent between adjacent entrances on the same direction.”

Michigan [48] recommends an unsignalized driveway spacing of 350 ft.

Minnesota [74], Texas [54][66], and Vermont [75] recommend a driveway spacing of 360 ft.

Mississippi [49] recommends that for a commercial drive with greater than 50 peak hour trips and a driveway ADT of less than or equal to 2000 ADT the driveway spacing by 350 ft. and for a commercial drive with less than or equal to 50 peak hour trips and ADT less than 2000 ADT the driveway spacing be 100 ft.

Missouri [50] recommends that for principal and minor arterials with non-traversable medians the spacing be 220-330 ft. and 165 ft. respectively, and for principal and minor arterials with traversable medians, the spacing be 440-660 ft. and 330 ft. respectively.

Montana [57] provides a spacing of 325-375 ft. on undivided highways and 150 ft. on divided highways.

Nebraska [76] permits access to all properties but recommends that the consolidation of driveways be considered wherever feasible.

Nevada [77] recommends a spacing of 350 ft. on principal arterials with full access driveways. On principal arterials where only right-turns are allowed, a spacing of 250 ft. is recommended, and on minor arterials, a 250-ft. spacing is recommended.

New Mexico [78] recommends the spacing for principal and minor arterials as shown in Table A-3.

Table A-3: New Mexico Recommended Driveway Spacing

Arterial Type	**Non-Traversable Median (ft.)**		**Traversable Median (ft.)**
	Full Access	Partial Access	
Principal arterials	1,320	450	450
Minor arterials	660	400	400

New York [51] states that the optimal driveway spacing cannot be precisely determined, but there is a consensus that the driveway spacing on the order of (300 to 500ft), depending on the operation speed on the highway and traffic generation of the development is desirable to reduce accidents and maintain the flow of traffic.

North Carolina [79] permits, "normally, one driveway connection for a single property or commercial site. However, the NCDOT may consider additional entrances or exits as justified and if such access does not negatively impact traffic operations and public safety. Only one combined entrance and exit connection will be permitted where the frontage is less than 100 feet. 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 feet. However, on routes with safety, congestion, or operational problems, 1,000 feet or more may be required between the centerline of any left turn access points and any adjacent street and driveways. The minimum distance between driveways does not apply to service drives not used by the general public."

Ohio [80] recommends a driveway spacing of 425 ft.

Oregon [64] recommends 860 ft. spacing as the minimum access spacing to provide maximum egress capacity. For statewide highways with AADT greater than 5,000, the driveway spacing recommended is 800 ft. For regional highways with AADT greater than 5,000, the driveway spacing recommended is 500 ft.

Pennsylvania [53] permits "only one access to be permitted for a property. An additional access or accesses shall be permitted if the applicant demonstrates that an additional access or additional accesses are necessary to accommodate traffic to and from the site and it can be achieved in a safe and efficient manner. The municipality shall restrict access to right turn only ingress and egress or to another state-maintained road or local road if safe and efficient movements cannot be accommodated." For principal arterials, the desirable spacing is 600 ft., and for minor arterials, this desirable spacing is 400 ft.

South Carolina [18] recommends a driveway spacing of 325 ft.

South Dakota [65] recommends that the driveway spacing be between 100 and 660 ft., depending on the level of development.

Virginia [81] provides different spacing regulations from different types of intersections/access. For principal and minor arterials, "spacing from full access entrances and directional median to other full access entrances and any intersection or median crossover is 565 ft. and 470 ft., respectively. For principal and minor arterials, the spacing from partial access one or two-way entrances of any type of entrance, intersection or median crossover is 305 ft. and 250 ft., respectively."

Washington [55] provides different spacing guidelines by class. "In Class 1 (mobility is the primary function), the spacing is 1,320 ft. In Class 2 (mobility is favored over access), the spacing is 660 ft. In Class 3 (balance between mobility and access in areas with less than maximum buildout), the spacing is 330 ft. In Class 4 (balance between mobility and access in areas with maximum buildout), the spacing is 250 ft. Finally, in Class 5 (access needs may have priority over mobility), the spacing is 125 ft."

West Virginia [82] states that "frontages of 50 ft. or less should be limited to one driveway. Normally, not more than two driveways are permitted on any single property tract or business establishment." The recommended driveway spacing is 230 ft.

Wyoming [83] recommends a spacing of 330 ft.

A summary comparison table of the findings from the review of state practices is shown on the following page in Table A-4. Recommended spacing (for developed arterials with 45 mph design speed) varied for each state, however a common recommended spacing is about 350 ft. Several states also made a distinction in spacing between full-access driveways and restricted-access driveways. In cases where this distinction was made, the spacing between restricted-access driveways is less than that for full-access driveways.

Table A-4: Comparison Summary of State Agency Driveway Spacing Guidelines

State	Full Access Spacing (ft.)	Restricted Access Spacing (ft.)
Alabama	660 (without median) | 1,320 (with median)	440 (with and without median)
Colorado	325	--------
Connecticut	2 entrances on frontage between 50 and 100 ft.	--------
Delaware	350	--------
Florida	245	--------
Georgia	230 (without right-turn lane) | 369 (with right-turn lane)	--------
Idaho	150	--------
Illinois	2 entrances for average commercial property | 440-660 (high-traffic generators)	--------
Indiana	350	--------
Iowa	300-600	--------
Kansas	300	--------
Kentucky	1,200	--------
Louisiana	550	225 (with non-traversable median)
Maine	265	--------
Maryland	20 (tangent between adjacent entrances)	--------
Michigan	350	--------
Minnesota	360	--------
Mississippi	350 (> 50 peak hour trips) | 100 (< 50 peak hour trips)	--------
Missouri	Principal Arterial: 220-330 (w/ RM) / 440-660 (w/ TWLTL) | Minor Arterial: 165 (w/ RM) / 330 (w/ TWLTL)	--------
Montana	325-375 (undivided) | 150 (divided)	--------
Nevada	350 (principal arterials) | 250 (minor arterials)	250
New Mexico	Principal Arterial: 1,320 (w/ RM) / 450 (w/ TWLTL) | Minor Arterial: 660 (w/ RM) / 400 w/ (TWLTL)	450 (principal arterial) | 400 (minor arterial)
New York	300-500	--------
North Carolina	One access per 100 ft. frontage | 600 (high-traffic generators)	--------
Ohio	425	--------
Oregon	500-860	--------
Pennsylvania	600 (principal arterials) | 400 (minor arterials)	--------
South Carolina	325	--------
South Dakota	100-660	--------
Texas	360	--------
Utah	350	--------
Vermont	360	--------
Virginia	565 (principal arterials) | 470 (minor arterials)	305 (principal arterials) | 250 (minor arterials)
Washington	125-1,320 (depending on mobility vs. access needs)	--------
West Virginia	230	--------
Wyoming	330	--------

Corner Clearance Distance from Intersection

Figure A-1 shows a sample diagram of the corner clearance from intersections. For the sake of comparability and brevity, only corner clearances for roads with the 45-mph posted speed roads are presented here, with other qualifiers noted for each state as they pertain.

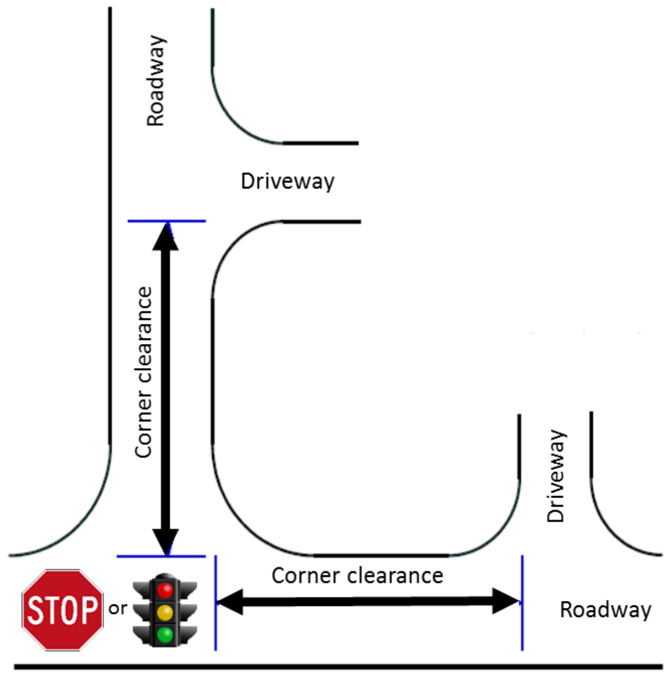

Figure A-1: Corner Clearance from Intersections (adapted from [18]*)*

Alabama [56] provides corner clearances in terms of median treatment and connection type as presented in the Table A-5 and Table A-6 below.

Table A-5: Corner Clearance in Alabama (Without Median) [56]

Connection Type	Corner Clearance (ft.)
Right-in (upstream only)	250
Right-out (downstream only)	250
Right-in/Right-out	275
Full Access (unsignalized)	660
Full access signalized	1320

Table A-6: Corner clearance in Alabama (With Median) [56]

Connection Type	Corner Clearance (ft.)
Right-in (upstream only)	125
Right-out (downstream only)	125
Right-in/Right-out	250
Full Access (unsignalized)	660
Full access signalized	1320

Connecticut [42] permits corner clearances of 10 ft. for commercial driveways.

Florida [69] recommends a corner clearance of 245 ft.

Idaho [44] provides both upstream and downstream corner clearances based on the median treatment and type of intersection (signalized vs. non-signalized). For signalized intersections, the downstream corner clearance allowed, for both traversable and non-traversable median roadways is 200 ft. For non-traversable median roadways, the upstream corner clearance allowed is 100 ft. while for traversable median roadways the upstream corner clearance is 200 ft. The allowable corner clearance to a median opening is 25 ft. For non-signalized intersections, the downstream corner clearance for traversable and non-traversable medians are both 95 ft. For non-traversable median roadways, the upstream corner clearance allowed is 100 ft. while for traversable median roadways the upstream corner clearance is 200 ft. The allowable corner clearance to a median opening is 25 ft.

Kentucky [46] permits a corner clearance of 1,200 ft. for commercial, industrial, and recreational driveways.

Maine [47] permits a corner clearance of 75 ft. for unsignalized driveways and 125 ft. for signalized driveways.

Maryland [62] recommends a minimum corner clearance of 200 ft. on primary arterials, and 100 ft. on secondary arterials.

Michigan [48] permits upstream and downstream corner clearances for signalized intersections of 230 ft. and 460 ft. respectively; and upstream and downstream corner clearances for non-signalized intersections of 170 ft. and 230 ft., respectively

Minnesota [74] recommends an upstream corner clearance of 650 ft. and downstream corner clearance of the greater distance between the stopping sight distance or the length of an acceleration lane.

Mississippi [49] recommends a 125 ft. corner clearance, with an exception to use as low as 50 ft. for right-in/right-out drives.

Missouri [50] recommends a minimum corner clearance of 440 ft. for principal arterials and 330 ft. for minor arterials.

Nevada [77] specifies corner clearances by driveway type. For residential drives, the allowable corner clearance is 150 ft. For commercial drives, the allowable corner clearance is 350 ft. And for public or private roads the corner clearance allowed is 660 ft.

North Carolina [79] specifies a corner clearance of at least 100 ft., where property frontage allows, and at no time less than 50 ft.

Ohio [80] stipulates that corner clearance shall be the same as the state driveway spacing, which is 425 ft.

Pennsylvania [53] recommends that for principal arterials, the corner clearance be 600 ft., and for minor arterials, 400 ft.

South Carolina [18] recommends a corner clearance of 325 ft. for full access drives and 150 ft. for right-in/right-out driveways.

Texas [54][66] like Ohio stipulates that corner clearance shall be the same as the state driveway spacing, 360ft.

Vermont [75] and Washington [55], like Texas and Ohio, use spacing standards to stipulate corner clearance, 360 ft. If this value cannot be met, the following provisions are made. With a restrictive median, if the approaching intersection is right-in/right-out or right-in only, the corner clearances may be 115 ft. and 75 ft., respectively. With a restrictive median, if the departing intersection is right-in only or right-in/right-out, the corner clearances may be 230 ft. and 100 ft., respectively. Without a restrictive median, if the approaching intersection is full access or right-in only, the corner clearances may be 230 ft. and 100 ft., respectively. Without a restrictive median, if the departing intersection is full access or right-out only, the corner clearances may be 230 ft. and 100 ft., respectively.

Table A-7: Comparison Summary of State Agency Corner Clearance Guidelines

State	To Signalized		To Unsignalized
	Full Access (ft.)	**Right-In/Right-Out (ft.)**	**Full Access (ft.)**
Alabama	1,320	275 (w/out RM); 250 (with RM)	660
Connecticut	10	--------	--------
Florida	245	--------	--------
Idaho	200 (downstream) | 200 (upstream w/ RM); 100 (upstream w/out RM)	--------	95 (downstream) | 100 (upstream w/ RM); 200 (upstream w/out RM)
Kentucky	1,200	--------	--------
Maine	150	75	--------
Maryland	200 (primary arterials) | 100 (minor arterials)	--------	--------
Michigan	460 (downstream) | 230 (upstream)	--------	230 (downstream) | 170 (upstream)
Minnesota	Greater of acceleration lane or SSD (downstream) | 650 (upstream)	--------	--------
Mississippi	120	50	--------
Missouri	440 (principal arterials); 330 (minor arterials)	--------	--------
Nevada	350	--------	--------
North Carolina	100 (no less than 50 in limited frontage situations)	--------	--------
Ohio	425	--------	--------
Pennsylvania	600 (principal arterials); 400 (minor arterials)	--------	--------
South Carolina	325	150	Same as signalized
Texas	360	--------	--------
Vermont	360	230 (downstream); 115 (upstream)	--------
Washington	360	230 (downstream); 115 (upstream)	--------
West Virginia	15 (30-50 desirable)	--------	--------

West Virginia [82] allows "a minimum of 15 feet at the near and far sides of intersection, but 30 to 50 ft. is desirable. If the intersection is signalized, the near side clearance should be two or more times the far side distance."

A comparison table of the findings from the review of state practices is shown in Table A-7. Several states distinguished between upstream (approaching) and downstream (departing) corner clearances, while a majority cite one value. Recommended corner clearances (for developed arterials with 45 mph design speed) varied for each state, ranging from 10 ft. to 1,320 ft. However, most corner clearance standards were in the roughly 200-400 ft. range.

Restricted Access Recommendations

Florida [69] stipulates that if it is not possible to meet minimum corner clearance according to the FDOT rules, 125 to 230 feet should become the new minimum corner clearance goal. In these cases of less than minimum corner clearance, left-turns from these driveways should be prohibited (or limited).

Illinois [59] stipulates 3/4 access (no left out) "on high-volume divided arterials where prevented left-turn volume from the entrance is relatively low, and recommends consolidating access on adjacent properties with continuous parking lots and separate parcels assembled under one entity/usage."

Kansas [45] states that "right-in/right-out access is typically used on highways in developed areas where the influence areas of adjacent access points provide a window for right-turns but not left-turns."

Maryland [62] recommends that "commercial right-in/right-out be used on all divided highways with posted speeds above 40 mph."

Minnesota [74] recommends the following: "when high traffic volumes result in a lack of gaps for entering and exiting traffic to safely cross, left turn movements and crossing movements may be restricted; when a driveway and an intersection are closely spaced such that a vehicle following a turning vehicle cannot anticipate where the lead vehicle will turn, right-in movements may be restricted; when an access is located where it may be blocked by queuing traffic from a nearby intersection, left-turn movements, crossing movements and right-out movements may be restricted; where an access is needed for a specific movement such as a one-way driveway, the driveway may be limited to right-in-only or right-out-only; on a divided highway where a lack of gaps prevent entering traffic from safely weaving across multiple lanes to make a left-turn or U-turn, and a reasonably convenient and suitable alternative route is available, right-out movements may be restricted; or where adequate sight distance does not exist for a specific movement, that movement may be restricted."

New Jersey [84] stipulates that "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 traffic volumes are reached, close the left-turn access in accordance with New Jersey Code; 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 New Jersey Code."

New Mexico [78] states that "restrictions to full left-turn access may be required due to safety or operational deficiencies that would be expected if a full access median were implemented. Restricted movements should be prohibited through geometric design and channelization supplemented by signing in accordance with the MUTCD."

North Carolina [79] stipulates that "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; thus, restricting the driveway operation to right turns only."

Pennsylvania [53] states that "the municipality shall restrict access to right turn only ingress and egress or to another state maintained road or local road if safe and efficient movements cannot be accommodated."

Texas [54] stipulates that "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 access 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."

Utah [85] recommends that "roadway approaches and driveways that are located too close to an intersection can affect signal operation. Consider restricting access to "Right In/ Right Out" operation."

Table A-8: Comparison Summary of State Agency Restricted Access Recommendations

State	Restrict to Right-In/Right-Out
Florida	When minimum acceptable corner clearance is not met
Illinois	"On high-volume divided arterials where prevented left-turn volume from entrance is relatively low"
Kansas	"On highways in developed areas where the influence areas of adjacent access points do not provide window for left-turns"
Maryland	"On all divided highways with posted speeds above 40 mph"
Minnesota	"When high traffic results in a lack of gaps for entering/exiting traffic and/or when blocked by intersection queue"
New Jersey	If signalized spacing cannot be met or undivided highway becomes divided
New Mexico	If safety or operational deficiencies are expected
North Carolina	If driveway is in influence area of the intersection
Pennsylvania	"If safe and efficient movements cannot be accommodated"
Texas	"Where adequate access connection spacing cannot be achieved"
Utah	For "roadway approaches and driveways that are located too close to an intersection"
Virginia	In situations with limited corner clearance

Virginia [81] states that "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."

A comparison summary of the findings from the review of different state practices is shown in Table A-8. A common recommendation was where gaps in traffic did not adequately allow for left-turn access. Another common recommendation was for driveways in influence areas of intersections (and/or where inadequate corner clearance was provided).

Summary of the State Practices

Different states have their own access management policies as the access management impacts vary for different roadway geometric and traffic operational conditions. Some state DOTs often update their manuals/policies to adjust the guidelines with the changing traffic volume, geometric conditions and land use patterns.

A. 3 Review of Published Research

The purpose of this section of the literature review is to provide an overview of research method, findings, and design guidelines, simulation parameters, and/or other recommendations from past research relevant to the research of this project. At the end of this section, there will be a summary of the literature review main findings.

Non-traversable (Raised Medians)

Eisele et al. (2005) [86] investigated the" impacts of raised medians on travel time, speed, and delay." The authors performed micro-simulation in VISSIM (and signal optimization in SYNCHRO) on three existing corridors and three theoretical corridors with different driveway spacing, median treatments, and traffic volumes. The three test corridors ranged in length, signal and access density, median opening spacing, number of lanes, existing ADT, and estimated future ADT. The theoretical corridors were given different lane, driveway density, driveway spacing, and estimated future ADT characteristics to study the effects of these variables on the MOE's (i.e., time, speed, and delay). Both 2-lane and 3-lane (in each direction) scenarios were tested, with the ADT of the simulated corridors ranged from 18,000 to 48,000, raised median opening spacing of 660 ft., and the driveway spacing ranging from 165 ft. to 660 ft. In all theoretical corridors, an equal number of driveways was assumed on each side of the road, driveway centerlines were aligned, and trips generated from the driveways were estimated from the ITE Trip Generation Manual, and the trips entering and exiting driveways were equally divided between left-turning and right-turning movements. Results from simulation of the existing corridors showed differing travel time effects for each corridor, revealing access management impacts to be case specific. For the lowest length corridor, decreases in travel times were found for both low and high ADT levels tested. For the longest and second longest corridors studied, however, travel times were shown to increase with the addition of the raised median. Results from the theoretical corridor simulation studies showed a general increase in travel time for through moving vehicles with the addition of the raised median, with an average reduction in speed of 3 mph. The authors explained that this increase in travel time (and decrease in speed) with the addition of raised medians was due to more U-turn traffic at signalized intersections as well as added through volume traffic from right-turn-U-turn movements.

Chowdhury et al. (2005) [5] evaluated the effect of different left turn treatment alternatives on network-wide average delay per vehicle. Microsimulation in CORSIM and signal optimization in SYNCHRO were used to analyze the alternative scenarios. The sites analyzed included divided, undivided, and 2-lane roads, each having signalized intersections on both ends, and unsignalized driveways leading to major traffic generators exiting onto the main road. The five alternatives to direct left turns analyzed were "(1) No restriction of direct left turns, (2) No direct left turns in or out of driveways with diverted traffic making a U-turn at the next available intersection, (3) No direct left turns in or out of driveways with diverted traffic making a U-turn at the mid-block, (4) Use of a Jughandle left-turn at the signalized intersection to accommodate left turns, and (5) No direct left turns except for on one driveway consisting of a concentration of all driveway volume." Each classification of roadway and alternative was analyzed for varying levels of mainline and driveway volumes. In general, it was found that increases in mainline volume had a far lesser impact on driveway volume than on network-wide average delay per vehicle. For multilane divided highways, the direct left-turn alternative was preferable until the 650 vphpl volume threshold was reached, beyond which, the RTUT with U-turns occurring at nearest signalized intersections became preferable. The concentrated left turn treatment performed very well operationally and was therefore recommended where the existence of internal circulation allows for its implementation. Overall, the study found the "operational differences between direct-left-turn movements and the U-turn alternative movements to be negligible," and that operational impacts need to be assessed on a site-by-site basis.

Zhou et al. (2002) [6] studied the U-turn as a substitute to direct left turns from driveways and the resulting operational effects. Field data were collected using cameras at eight study sites (all 6-lane sites with signal spacing less than 2-miles) in order to compare the delay experienced by DLT and that of RTUT vehicles. From this data, two exponential regression equations for total delay and two exponential regression equations for travel time were developed for the DLT and RTUT movements respectively. For the DLT equation, regression variables included left-turn-in volume, through volume, left-turn volume, and the split (distribution of through volume in either direction). For the RTUT equation, regression variables included through volume, RTUT flow rate, speed, and the SPLIT. Curves for varying roadway characteristics can be developed from these equations allowing for estimation of travel time and delay of DLT and RTUT vehicles. Based on an overview of these curves, it can be demonstrated that "U-turns can have better operational performance than direct-left-turns under certain traffic conditions."

Liu et al. (2007) [32] studied U-turns and their operational effects in place of direct left turns testing travel time and delay. The study also examined the average running time "for vehicles making right-turn U-turn left turns at varying separation distances between driveways and U-turn locations." Using field data from 34 roadway segments, the study analyzed travel time and delay data for "direct left turns, right turns followed by U-turns at median openings, and right turns followed by U-turns at intersections." Results from the study showed that "with the increase of driveway and major road through volumes, delay for direct left-turns increases," and the delay from a right-turn-U-turn movement can be 1-3 seconds less on average as these volumes increase. In short, the higher the roadway volumes, the more attractive the right-turn-U-turn at a median alternative is from a delay standpoint. Regardless of the volumes on the road, vehicles making right-turn-U-turns at signalized intersections experienced more delay than the other two alternatives. On average over all 34 segments, the median U-turn alternative performed the best from a delay perspective, with the direct left turn being a close second, and the signal U-turn being a distant third. Results from the study for the second objective created a travel time (of left-turning alternative movements) comparison graph linking separation distance with total travel time. The travel time of U-turning vehicles, making U-turn at signalized intersections, far exceeded those of direct left-turners and U-turning vehicles at mid-block median openings.

Yang and Zhou (2004) [87] evaluated the travel time and delay of direct-left-turns versus RTUT movements using a CORSIM-based simulation approach. Data was collected from six existing sites in order to calibrate the simulation model, which was then used to estimate delays and travel times for DLT and RTUT movements at varying levels of driveway volume (150-350 vph) and two-way through volume (3000-7000 vph). Resulting curves for delay and travel time were generated for each site-based model for a total of 6-sets of curves. From these curves, breakpoints (points at which RTUT movements experienced favorable travel times/delays) could be determined for the different driveway and through volume thresholds. While these breakpoints vary by site, the general trend observed was that the lower the driveway volumes, the higher the mainline through volume at the breakpoint, and vice versa.

Reid and Hummer (1999) [88] compared traffic operations for a typical arterial under Median U-turn Crossover (MUT), two-way-left-turn-late (TWLTL), and Super-Street Median Crossover (SSM) design using microsimulation in CORSIM. The ITE Trip Generation Manual was used to assign trip rates for driveways along the corridor, and these trip rates were kept constant between each of the three scenarios tested. Four time periods, morning-peak, noon, mid-day, and afternoon peak hour were tested, with each time period having varying driveway and through-trip intensities. SYNCHRO was used for optimization of signal timings, and the same set of random number seeds were used for each scenario for uniformity. The results of the simulation run show that while the TWLTL scenario had fewer average stops per vehicle than the MUT and SSM scenarios, it had a higher system travel time and average speed. The MUT performed best in these categories on average. When considering the four different time periods analyzed, the results showed that the MUT and SSM scenarios outperformed the TWLTL in peak hours but also performed similarly to the TWLTL in off-peak hours. In other words, this research found that the alternative designs did not compromise travel times during off-peak hours.

Shadewald et al. (2003) [89] studied the effects of varying access control improvements on a test-corridor using total delay (sec/veh), travel time (VHT), speed (mph), and fuel efficiency (MPG) as measures of effectiveness. SYNCRO and NETSIM were used to model the different scenarios, which included (1) Existing Conditions: 40 access points/mile, no center median, 5 signalized intersections, (2) Improved Access-Controlled Alternative: 25 access points/mile, addition of center median, addition of backage road, and (3) Full Access-Controlled Alternative: 10 access points/mile, fully center median controlled, backage roads. Driveway trips were estimated using the ITE Trip Generation Manual. The results from the study showed that the Improved and Full Access Control reduced total delay and travel time, while increasing fuel efficiency and speed. The improved access scenario (2) increased capacity by 25-45 percent, decreased total delay by 65-170 seconds per vehicle, decreased stop delay by 100-200 seconds per vehicle, and increased speeds by 20-33 percent. The full access-controlled scenario (3) increased capacity by 50-100 percent, decreased total and stop delay per vehicle by 83-91 percent, and increased speeds by 14-24 mph, while reducing fuel consumption by 30-40 percent. An important note about this study is that right-of-way and feasibility of altering and/or constructing new backage roads was not considered.

Lu et al. (2005) [19] proposed minimum acceptable offset distances for vehicles making RTUT on 4/6-lane urban/suburban multilane divided arterials, "with offset distance defined as the separation distance between the driveway exit and downstream median opening or signalized intersection" at which the U-turn will take place. Determination of the minimum offset distances was made by taking into account crash analysis, conflict analysis, and operations analysis of 68 field sites. The minimum offset distances recommended by the study varied by U-turn location (median opening vs. signalized intersection) and by the number of lanes (4 vs. 6 or more). The resulting recommended offset distances are shown in the following Table A-9.

Table A-9: Offset distance for U-turn

U-turn Location	Number of Lanes	Offset Distance (ft.)
Median Opening	4	400
	6 or more	500
Signalized Intersection	4	550
	6 or more	750

Carter et al. (2005) [90] studied the "operational and safety effects of U-turns at signalized intersections." The operational impacts were estimated by quantifying U-turn behavior at 14 sites which had protected turn phases along with exclusive left-turn lanes. The research team collected saturation headway measurements and volume counts at all sites in order to develop a regression equation for estimating a saturation flow adjustment factor in terms of U-turn percentage and the existence of conflicting right-turn protected overlap, which were both found to be statistically significant regression variables. This regression equation showed a "1.8% saturation flow rate loss for every 10% increase in average U-turn percentage, with an additional 1.5% loss per 10% U-turns where there is an opposing protected-right-turn overlap from the cross-street." The safety impacts were estimated by analyzing the crash histories involving U-turns at 78 sites. The crash analysis indicated that 65 of 78 sites "had no collisions involving U-turns in the 3-year study period," and the sites that had collisions "had crash rates ranging from 0.33 to 3.0 collisions per year." Overall, the study found that both operationally and safety-wise, "U-turns do not have a large negative effect at signalized intersections," with minimal crash histories involving U-turns and only 1.5s of increased stopped delay per 10% increase in U-turns. However, a conclusion of note from the study was that protected right-turn overlap on the cross street does have an adverse impact both operationally and safety-wise in intersections where U-turns are allowed/prevalent.

Qi et al. (2013) [91] developed guidelines for "operationally effective raised medians and alternative movements on urban roadways." The critical design issues addressed included median widths, placement, median left-turn lane lengths, and directional versus full median openings. The study was performed by reviewing national and peer-reviewed literature, conducting a nationwide survey of traffic engineers, conducting field studies, and performing simulation analysis. An overarching finding from the research was that there were fewer existing research initiatives relating to the operations of raised medians than there were concerning their safety. Additionally, the existing research seemed to be inconclusive about whether raised medians were more operationally favorable to TWLTLs as there are a plethora of factors influencing their effectiveness. The research also found directional medians within an intersection influence area to be less favorable than full median openings from an operational standpoint. The guidelines developed from the initiative were: (1) An ADT greater than 20,000 vpd warrants consideration of implementing a raised median; (2) Typical median width should be at least 16 ft., however on roadways allowing U-turns, widths need to be wider to accommodate the design vehicle. The authors developed recommended minimum median widths and necessary right-of-way (ROW) in order to provide adequate space for U-turn movements based on a swept path analysis. Based on this analysis, for the passenger car design vehicle (P), the minimum median width on a four-lane road with a dedicated left-turn lane is 30 ft., and the necessary right-of-way for the road is 100 ft.; (3) Median openings should be placed to provide openings at all public roads and major traffic generators, and additional openings should be provided so as to not exceed 2,640 ft. to minimize travel distance for right-turn-U-turn movements. (4) Median opening lengths should be at least 40 ft. (5) Lengths of deceleration lanes at median openings should be determined depending on speed and assumed speed differential. The operational impacts of shorter-than-approved left-turn lanes were found to be minimal in isolated instances. However, where short left-turn lanes were used successively on a corridor, negative impacts compounded; (6) Median left-turn lanes should be considered according to previously established left-turn lane warrants; and (7) Full median openings are recommended under most circumstances, though directional median openings can be considered as replacement if the opening is in the influence area of an intersection.

Chowdhury et al. (2004) [92] conducted a survey aimed at determining the state of knowledge and practice in providing alternatives to direct-left turns. A survey was sent to all 50 states, with responses received from half (25) of them. The survey results provided a basis for an ongoing inventory of current practices at the State Agency level. Results from the survey indicated that most states did not have formal policies or guidelines for restricting direct-left-turn movements and/or for providing alternate movements for left-turn traffic in the case of restricting such movements. Instead, it was found that "most states handle these situations on a case-by-case basis," likely due to the fact that there is no national standard in place for prohibiting direct-left-turn movements. When these movements are accommodated, the majority of states prefer mid-block U-turns or Jughandle. The survey study concluded that there is a lack of standards at the state agency level concerning restriction of direct left-turns and how to accommodate deterred direct left-turn traffic. The paper also recommends additional research towards the development of national policies and guidelines for these access management strategies.

Access Density, Restriction, and Corner Clearance

Siddiqui (2011) [14] investigated "the operational impacts of access modifications at midblock and corner driveways on 5-lane roads with a TWLTL". Microsimulation in VISSIM (with signals optimized in Synchro) was used to model 142 different theoretical models (calibrated from a field-studied road model) with varying driveway locations' (midblock, corner) density (0-44 access points /mile), and restrictions (full access, right-in/right-out, combination of both) while also varying mainline traffic volumes (1500, 1700, and 1900 vph

– each direction) and driveway volumes (25 to 200 vph). The main finding of the research was that “mainline volume has a much greater effect on driveway operations than on increased driveway density. In other words, cases with high access density and high driveway volume, but low mainline volume did not have significant impacts on driveway delays.”

Gluck et al. (1999) [93] investigated the relationship of traffic operations to access spacing by conducting observational analysis at 22 sites in the Northeastern United States. Researchers recorded the number through vehicles that were affected by right turns at unsignalized driveways for major traffic generators without deceleration lanes in order to “estimate the percent of right lane through vehicles impacted by the right-turn-in movement as a function of right-turn-in volume.” A linear fit of the data revealed that the percentage of right lane through vehicles impacted was roughly 0.18 times higher than the right-turn-in volume. A cumulative distribution of impact length curve was prepared from the data and multiplied by the percentage of right lane through vehicles affected by right-turn-in movements to yield cumulative frequency distribution curves of impact lengths that show the percentage of through vehicles affected by right-turn-in movements for varying levels of right-turn-in volume at different distances from a driveway. These curves were then shifted to account for additional influence length (which included the car length and perception reaction distance) to yield curves for different levels of right-turn-in volume showing the percentage of cars impacted according to different influence lengths. These curves were then used to propose spacing guidelines for driveways according to both right-turn-in volume and spillback percentage (percent of impacted vehicles) allowed. For example, on a roadway with a 45-mph speed limit, driveways with right-turn-in volume less than 30 vph, and a 10% allowable spillback rate, a driveway spacing of 270 feet is proposed. The proposed guidelines were compared with existing state guidelines and found to fall within acceptable ranges.

Khan et al. (2016) [2] investigated the optimal number of driveway access points for a corridor from both operational and economic perspectives. Using data from traffic simulation, authors generated a multi-objective optimization problem which minimizes travel time and maximizes the number of access.

Lyles et al. (2009) [7] conducted a simulation study (in VISSIM) to assess traffic flow impacts of right-in/right-out treatments and develop guidelines for when such strategies should be implemented. A total of eight models were developed and simulated (6 simulating corner driveways and 2 simulating mid-block driveways). In each model, four variables were varied to determine their impact on right-in/right-out restricted driveways: Corner Clearance (150-350 ft.), Mainline Volume (250-2000 vph), Driveway Volume (25-150 vph), and left-turn-in and –out volume (10-50 vph). In each model, five access control alternatives were tested: (1) no driveway, (2) right-turn-in only, (3) right-in/right-out, (4) left-turn-in and right-in/right-out, and (5) full access. Each model was calibrated to a field-observed site using average travel time and queue length. For changes in mainline volume, volume was assumed to change in both directions of travel but not at the other intersection approaches. Resulting U-turning traffic from access restriction was ignored in these tests and assumed to leave the network in the direction that it exited the driveway in question. In this study the measures of effectiveness were mainline traffic average delay (sec/veh), average delay (sec/veh) for left-turn-in and –out traffic, and 50th percentile queue length. These measures were expressed in individual plots according to the different aforementioned variables. The main finding of the research was that "increases in mainline volume had a greater impact on average delay/queue length for mainline traffic than increases in driveway volume. It was also found that impacts of increases in mainline, driveway, and left-turn volume were greater when corner clearance was less than 150 feet." Additionally, it was found that "the delay for left-out traffic was greater than delay for left-in traffic, and that the impact of driveway volume on average delay was greater as the mainline volume approached 1500 vph." Another key contribution of this research were guidelines/thresholds for implementing certain access restrictions. For both corner and mid-block driveways, it was recommended that left-ins and left-outs be restricted when mainline volume is greater than 1500 vph. Additional provisions for restricting these movements for mainline volumes less than 1500 vph included when corner clearance is less than 100 feet, driveway volume is greater than 150 vph, and left-turn-in/out volume greater than 50 vph.

Gan and Long (1997) [94] highlighted key operational effects due to inadequate driveway corner clearances. These problems include: "(1) blockage of driveway egress movement, (2) blockage of driveway ingress movement, (3) incomplete turning maneuvers in left-turn lanes, (4) conflict with intersection turning movements, (5) dual interpretations of right-turn signals, (6) merging bay vehicular conflict and reduced merging length, (7) insufficient weaving section length, and (8) emerging vehicular conflicts from driveways on right-turn bays." Driveway and intersection capacity are also negatively affected by inadequate corner clearance in that adequate gaps in platoons are not available for driveway egress traffic and right-turn egress from driveways in the intersection functional area reduces the saturation flow rate in the intersection.

Long and Gan (1997) [95] in a companion study to the one previously referenced, developed a model for determining minimum allowable corner clearances, similar to that in the HCM for computing saturation flow rates, in which an initial Minimum Corner Clearance (MCC) is adjusted according nine distinct site-specific factors (i.e., facility type, median type, driveway traffic volume etc.). This model makes up for deficiencies in existing models which are rigid, discrete, and provided for little consideration of the many different driveway design features. The model also allowed for MCCs relative to unsaturated and saturated flow conditions.

Prassas and Chang (2000) [33] investigated the effect of arterial volume, driveway volume, and driveway interactions as measured by average speed, driveway delay, and driveway queuing. The CORSIM simulation study modeled single driveway and multiple-driveway scenarios to determine the effect of upstream and downstream driveways on each other. These studies found that – when compared with the single driveway case – as the number of driveways increases, the negative effects on the MOE's increases by a factor of 2 (for two driveways) and by a factor of 4 to 5 (for three driveways). Additionally, it was found that the addition of downstream driveways reduced driveway capacity of the first upstream driveway by 30-50%. Conversely, the downstream driveways showed improved capacity – when compared with the single driveway case – due to a sheltering effect at the upstream driveway.

Microscopic Traffic Simulation

Park and Schneeberger (2003) [13] proposed a 9-step process for calibrating VISSIM simulation models: "(1) measure of effectiveness selection, (2) data collection, (3) calibration parameter identification, (4) experimental design, (5) run simulation (6) surface function development, (7) candidate parameter set generations (8) evaluation, and (9) validation through new data collection". This process was applied to a case-study calibration scenario.

Important and relevant conclusions and recommendations from the outworking of this process include:

1. Run the simulation multiple times for each scenario
2. Use visualization in the calibration process. Ensuring that vehicle movements and traffic operations represent real-world expectations is crucial to calibration of microscopic simulation models
3. Identify controllable input parameters (and acceptable ranges of these parameters) which can be manipulated during the calibration process. Controllable input parameters in VISSIM include: "emergency stopping distance, lane-change distance, desired speed distribution, number of observed preceding vehicles, average standstill distance, waiting time before diffusion, and minimum headway."
4. Perform statistical comparison of chosen MOEs to verify model is calibrated.

Liu et al. (2012) [15] developed a procedure for developing and calibrating VISSIM models for U-turns as unsignalized intersections, including relevant design and parameter recommendations for such simulation. Researchers modeled U-turns using VISSIM's priority rules, in which lines are placed for turning vehicles defining the necessary headway and gap-time before a turning movement will be made. The other important factors involved in properly calibrating U-turning movements were U-turning speed and the percentage of vehicles turning to the outermost lane. These factors were varied in VISSIM, and U-turning capacities were compared with HCM U-turning capacities to yield mean absolute percent errors (MAPE) for different combinations. The optimal solution was found for both 4-lane and 6-lane roadways. For 4-lane roads, the combination of parameters with minimal MAPE was: Gap Time = 6.3 seconds, Turning Speed = 8 mi/hr., and Percentage of Vehicles to Outside Lane = 99%. For 6-lane roads, these optimal parameters were: Gap Time = 5.1 seconds, Turning Speed = 9 mi/hr., and Percentage of Vehicles to Outside Lane = 63%. These parameters yielded U-turn capacities very similar to those found in both field measurements and the HCM estimation model.

Siddiqui (2011) [14] provided a detailed description of modeling TWLTLs in VISSIM by using overlapping links and priority rules at all driveway turning movements and determined that VISSIM could successfully simulate TWLTL operations. The important parameters associated with the priority rules included minimum gap times for left-out, left-in from

TWLTL, and right-out movements. Field observation found these minimum gap values to be 3.1, 3.6, and 3.0 seconds respectively. As with many of the other VISSIM simulation research initiatives reviewed, Synchro was used to optimize signals for alternative scenarios. A warm-up time of 10 minutes was also used to 'populate' the network prior to collecting data. The base model was considered calibrated when travel time was within 2% of the recorded field value for both mainline directions of travel.

Economic Impact Assessment of Access Management

A number of states have performed or sponsored studies on the economic impact of access management. These studies are summarized below.

Maze (1997) [96] conducted case studies involving five corridors in Iowa that implemented different access management strategies. Access management strategies in these five corridors involved adding TWLTLs, consolidating driveway and installing raised medians. The author found that the sales volume of businesses along these five study corridors outperformed those in the surrounding communities. He also found that the business turnover (i.e., going out of business or moving to a different location) in these five corridors in Iowa was at or lower than the statewide average. To examine the perception of the impact of raised medians, surveys of businesses and customers were conducted. Among the businesses surveyed, only 5% reported retail sales tax losses. More than 80% of the businesses surveyed indicated that they did not receive any customer complaints after the completion of the access management projects. The customer survey results showed that the majority of participants (more than 90%) supported the access management projects.

Eisele and Frawley (1999 and 2000) [20]-[21] investigated twelve corridors in Texas. Among these corridors, ten had raised medians installed and two had raised medians removed. The authors surveyed businesses, customers and undeveloped land owners. The survey results indicated that among the businesses that operated before, during and after the construction of raised median on the study corridors, gasoline stations, auto repair shops, and other services indicated a small negative effect on gross sales (0.73% on average). For those businesses that had raised medians removed, they reported that, on average, the gross sales increased by 3.9% and passer-by traffic increased by 3.7%. Results of the customer survey on five corridors that had raised median installed showed that although a majority of customers indicated the raised median made access to adjacent businesses more difficult, their satisfaction of these businesses remain the same or higher. Undeveloped land owners indicated that they believed raised medians would increase the attractiveness of the undeveloped properties.

Vu et al. (2002) [22] studied the perceived economic impact of access management along six corridors in Western Washington. These six corridors had access management treatments such as adding raised medians to fully control access, converting full-access driveways to right-in/right-out driveways, and consolidating driveways. The authors conducted a survey of businesses and developed two statistical models. In the survey, 52% of the businesses indicated that the existing access management had a negative effect on their customer patronage and sales revenue. The authors developed a bivariate probit model and a simultaneous logit model to capture the perceptual inter-relationships between business accessibility and patronage. The results of developed bivariate model showed that businesses with higher willingness to pay to relocate to a different location, medium-sized businesses and businesses that are open 7 days of a week are more likely to perceive the impact of access management to be negative on patronage. Businesses in retail service are more likely to indicate that access management will not have an impact on patronage. The results of the developed logit model showed that businesses with a higher willingness to pay and medium-sized businesses are more likely to perceive the impact to be negative. On the contrary, businesses with shared driveways and convenience stores are more likely to perceive the impact to be more positive.

Plazak and Preston, 2005 [97] studied the economic impact of upgrading U.S. Highway 12, an arterial, to I-394, a freeway. The authors examined the overall economic trend of this corridor before and after upgrading. They found a positive impact on businesses along this corridor. Specifically, "office buildings, fast food restaurants and big-box retailers benefited" from the project. The authors reported that "land use was changed from residential development to retailing and then to office and service sector development in this corridor." In addition, they interviewed selected businesses and the results indicated that businesses had a favorable opinion of the project.

Gattis et al. (2008) [98] studied the economic impact of converting the Interstate 30 from "two-way operation to one-way operation." The authors examined the sales tax of 20 businesses before and after the conversion. They found that the conversion had no economic impact on businesses (neither positive nor negative). They also surveyed businesses at two different time points: the initial survey was conducted three-months after the conversion occurred, and the follow-up survey was conducted approximately one year after the conversion. The results from the initial survey indicated that 54% of the businesses believed the conversion hurt their property/business/organization. In the follow-up survey, 61% indicated that the conversion hurt their property/business/organization. The authors concluded that a significant number of businesses believed the conversion hurt their businesses.

Cunningham et al. (2010) [23] evaluated the economic impact of access management in corridors located throughout North Carolina. The authors surveyed businesses along corridors that had access management treatments (referred to as treatment sites), as well as those businesses located is similar roadways that did not receive access management treatments (referred to as comparison sites). Six of the treatment sites had a raised median installed and two had signalized intersections converted to signalized superstreets. The authors found that businesses located at treatment and comparison sites have about equal proportions of change in sales revenue. The majority of the businesses indicated on the survey that the reason for the lower revenue was the economy. The survey results indicated that more businesses at the comparison sites than the treatment sites indicated that the raised median would have a negative effect.

Alluri et al. (2012) [99] investigated the economic impact of converting a TWLTL to a raised median in Florida. The authors surveyed businesses to examine the perception of the impact of raised medians. About 37% of the businesses indicated that their number of customers decreased after the conversion and about 27% of the businesses indicated that truck delivery was negatively affected by the conversion. Businesses were also asked to rate the impact of conversion on their businesses using the following scale: major impact, minor impact and no impact. The results indicated that the majority of gas stations and auto-related businesses indicated that raised medians had a major impact on their businesses.

Riffkin et al. (2013) [100] studied “the impact of raised medians on retail sales in Utah.” The authors selected three study corridors that received raised median treatment and three control corridors from the nearby corridors that did not receive raised median treatment.

They found that the retail sales increases in the three study corridors. Moreover, the businesses located in "the study corridors performed as well as or better than those located in the control corridors." The authors also surveyed businesses. The survey results indicated that more businesses in the study corridors than the control corridors indicated that raised medians would have a negative impact.

In addition to the aforementioned studies conducted at the state level, there is one study that has examined the economic impact of access management at the national level [101]. In [101], the author surveyed more than 250 agencies and organizations at the local, state, and federal levels in an attempt to identify 20 case study sites where access management treatment restricts left turns to adjacent businesses. A total of nine corridors were selected, and these corridors are located throughout the U.S. The authors collected data such as sales volume, employment, property values, capital investment, vacancy and land use patterns of businesses and properties located along the study corridors. They found that gas stations, non-durable goods retailers, and service businesses had the greatest decline in sales volume and the highest rate of business failures after the left-turn restriction. On the other hand, grocery stores and restaurants had higher sales volume. The author also surveyed businesses and customers. In the business survey, 46% of the businesses indicated that the left-turn restriction had a negative effect on their businesses. The authors found that the perceived impact of restriction was different among businesses. Specifically, businesses located at the mid-block perceived the impact of left-turn restriction to be more negative. In the customer survey, the majority of the customers indicated that the left-turn restriction had no impact on their visit frequency to the businesses.

Summary of Previous Research Review

A review of the literature as it relates to operational impacts of raised medians (and thus indirect left-turn movements – U-turns), driveway density, corner clearance distance from an intersection, and left-turn-in and –out restriction revealed several similar trends. In general, past research has found that U-turns do not significantly negatively impact operations at signalized intersections, and that RTUT movements as alternatives to DLT movements "can have better operational performance under certain traffic conditions." Different studies did measure 'operational impact' through different measures of effectiveness (MOE's). Some studies analyzed delay to turning vehicles at driveways, while others investigated traffic operations along the mainline direction of travel by analyzing delay, travel time, and average speed for these movements. Several studies came to the similar conclusion that changes in mainline volume were more impactful to mainline traffic operations than other factors (i.e., access density and volume). A number of studies also noted that there are volume thresholds (driveway and mainline) at which access management techniques (RTUT instead of DLT; restricting left-in/left-out) become advantageous operationally. Additionally, past research initiatives have noted that increased access density has negative effects on both through traffic and driveway delays/capacities and have presented alternative methods of establishing guidelines for access spacing and corner clearance distance from an intersection according to these findings – which are comparable to current practice but (according to the claim of the research) more justifiable. Finally, there is a relatively established history of using microsimulation to operationally evaluate access management strategies; many of which use VISSIM and Synchro. Several studies have also commented on calibration processes for microsimulation and provided useful recommendations for parameter values to use in this process.

The economic impact of access management appears to be mixed. Studies performed in Iowa, Minnesota, and Utah found access management has a positive impact on the surrounding businesses. Studies in Arkansas and North Carolina found access management to have no impact on businesses (i.e., neither positive nor negative). The Texas and NCHRP 231 studies found that gas stations, non-durable goods retailers, and service businesses to be negatively affected by access management treatments. These findings suggest that the economic impact of access management is site-specific, and thus, no study's conclusion or recommendation can be applied to all situations.

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APPENDIX B ONLINE SURVEY AND TELEPHONE INTERVIEW RESPONSES

B. 1 Online Survey Results from State Transportation Agencies in the U.S.

B. 1. 1 Questions about General Access Management Practices

Question 1: In your state, which types of corridor-wide access management techniques are most common?

Among the 32 state DOTs, the most widely used access management practice was limiting and separating access points along a corridor as shown in Figure B-1: Common Access Management Practices of DOTs. 26 DOTs (81%[43]) mentioned they implement this driveway closure/separation. The second most common practice was the driveway restriction near the intersections, which was practiced by 24 DOTs (75%). Only 6 DOTs changed signal spacing which is challenging to implement once a corridor is developed.

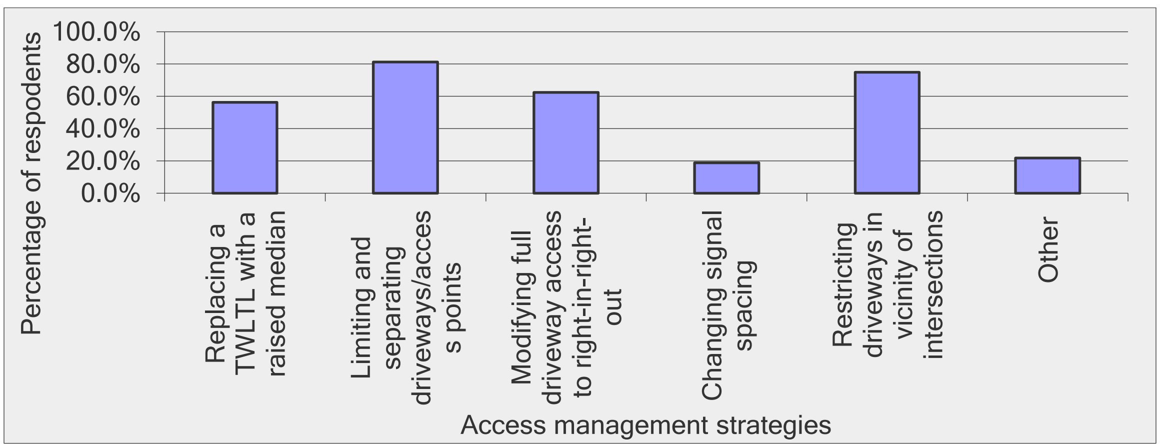


Figure B-1: Common Access Management Practices of DOTs

Apart from these access modification practices, seven DOTs also implemented other access management strategies, which include:

- Planning for signals/roundabouts before development
- Utilizing r-cuts and u turns
- Acquiring access rights if deemed necessary

Question 2: Is any of the following non-conventional access management strategy implemented in your state?

A majority of the DOTs mentioned (56%) that they did not practice any non-conventional access management strategies including Jughandle design and Michigan U-turn. Figure B-2 shows that only

[43] Percentage in parenthesis indicates the percentage of respondents for the particular question

three (9%) participants implemented Jughandle design, while six DOTs (19%) implemented Michigan U-turn.

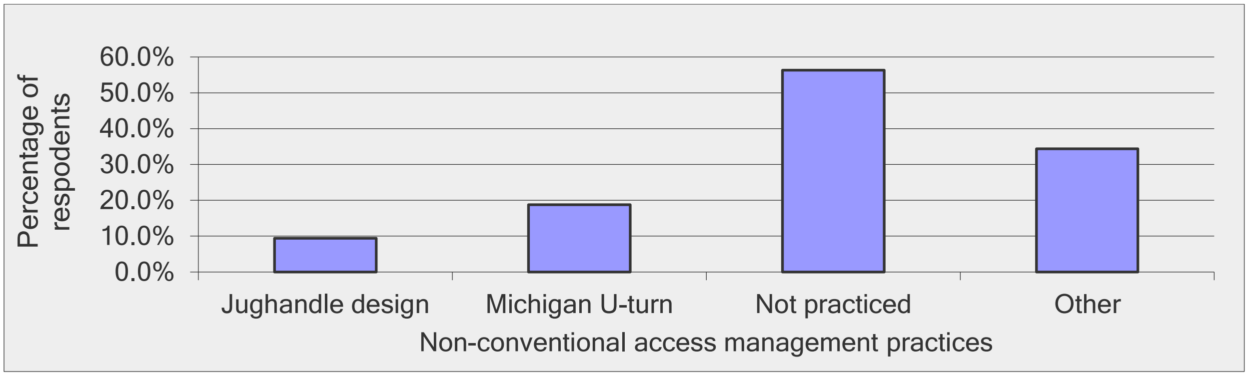


Figure B-2: Non-conventional Strategies Practiced by DOTs

Eleven DOTs (34%) implemented different types of non-conventional access management strategies which include:

- R-cut
- Diverging diamond interchange
- Continuous flow interchange
- Super-street
- J-Turns
- Quadrant intersection

Question 3: *Do you conduct any before-and-after study to measure the impact of implemented access management strategies for operational improvement?*

Only 10 DOTs (31.3%) conducted before-and-after studies for operational impact evaluation after implementing any access management project. However, 22 DOTs (69%) did not conduct the before-and-after study.

Following the accumulated survey responses, the reasons provided by DOTs for not conducting any before-and-after operational impact evaluation are given below:

- "Just the staffing and time are usually not available".
- "Most of our access management implementation comes at the time of redevelopment and there is a large increase in traffic generation, so before-after comparisons would not provide a lot of value."

- "No, most access management strategies and improvements are done within the scope of our Corridor Safety Improvement Projects. Projects are selected based on their return on investment (ROI) criteria and the severity of the safety concerns (accident history is included) however there are hardly ever funding available to do an after-implementation study to establish the level of the desired outcome".
- "We have limited resources - we want to do follow up, but it is not a priority - we do look at before-after crashes if someone asks"
- "Not as a matter of policy. We have re-visited corridors that have access control in place, but this is a case-by-case situation".
- "We don't have the resources, and this kind of study is not high on our priority list".

Question 4: *What are the measures of effectiveness used in the before-and-after study?*

Figure B-3 shows that among the 10 DOTs who studied before-and-after evaluation of operational improvements, five DOTs (50%) used crash number. The second most common MOE was the mainline travel time, which was used by four DOTs. Mainline average speed and intersection queue length were also used by DOTs.

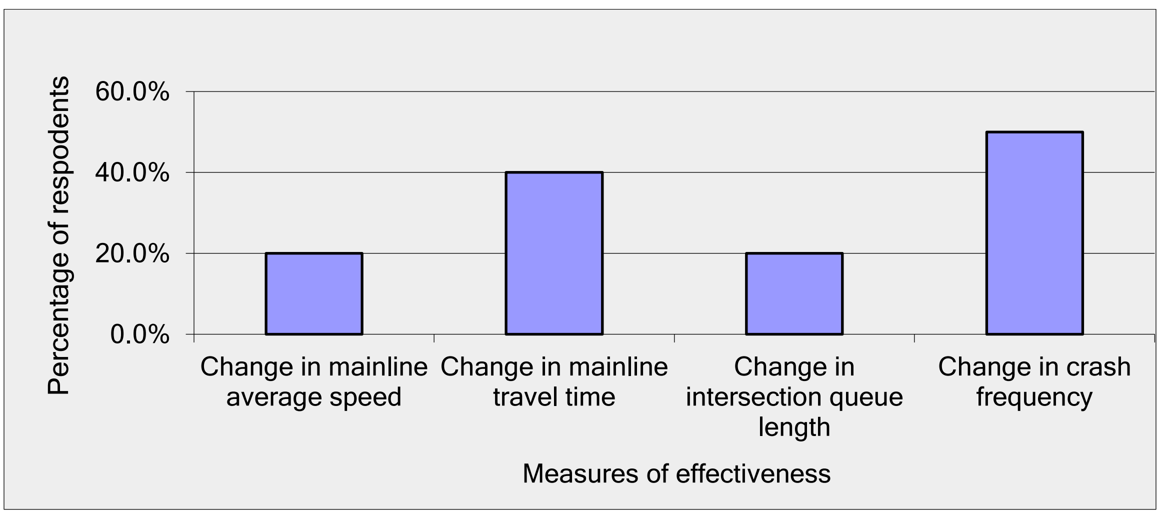


Figure B-3: MOEs for Before-and-after Study Conducted by DOTs

Question 5: *Has your state studied the economic impact of access management strategies?*

Thirty DOTs responded to this question. Only seven DOTs (23%) studied the economic impact of access management strategy. A majority of the participants (23 DOTs) did not study the economic impact.

Question 6: *Do your access management design standards consider economic impact?*

Thirty-one DOTs responded to this question. 21 DOTs (68%) did not consider economic impact in their access management design standards. Only 10 DOTs (32%) considered the economic impact in their design standards.

Question 7: *Is there any interest to consider economic impact in your access management design standards?*

Among the 21 DOTs who did not included economic impact in access management design standard, 15 DOTs (71%) wanted to consider economic impact in their access management design standards in future. However, six DOTs (29%) did not have any plan to do so.

B. 1. 2 Questions on Median Treatment

Question 1: *Which conditions or guidelines dictate the placement of median openings?*

Figure B-4 shows the conditions/guidelines which dictate the median opening placement. Thirty-one DOTs responded to this question. Twenty-two DOTs, 71%) placed median openings after a thorough traffic impact study. Eighteen DOTs (58%) followed their state manual to place the median opening. Five DOTs (16%) provided opening for all divided highways at all public roads.

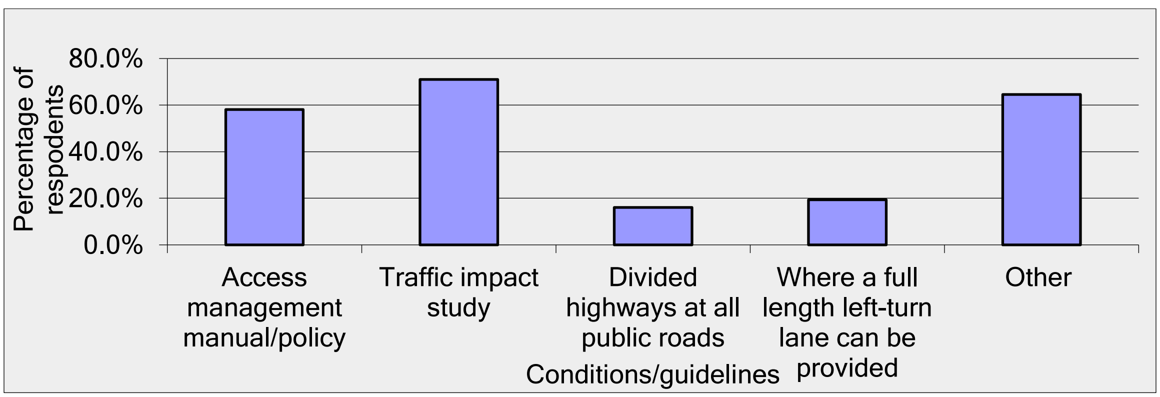


Figure B-4: Conditions Dictating the Median Opening Placement

Twenty DOTs provided median opening for several other reasons. As per the DOTs responses, the reasons are:

- "Future signals/roundabouts planning"
- "Roadway Design Manual and new driveway regulations provide median opening criteria"
- "Safety Assessment study and accident history"
- "We have standards, but in dense areas we look at a number factors (potential queue, volumes, availability of other means for left turns)"
- "Based on typical section, sight distance and crash study"

- “Engineering analysis during design phase of projects”
- “Documented policy in Roadway Design Manual”
- “Design policy - 1760 feet between median openings”
- “Right-of-way negotiations / legal negotiations”
- “Negotiated around 1 mile spacing”
- “Benefit analysis for safety and operational impacts”

Question 2: *Given that appropriate spacing is available, what other factors are important in determining whether a median opening can be placed?*

Twenty-six DOTs responded to this question. Among them, seven DOTs (39%) mentioned that they considered mainline through traffic volume while providing a median opening, as shown in Figure B-5.

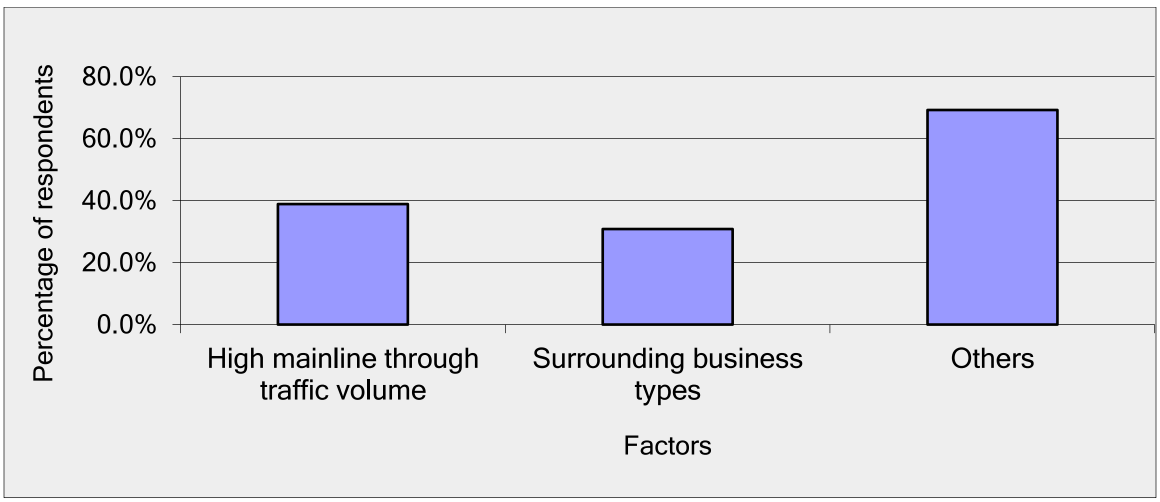


Figure B-5: Additional Factors for Median Opening Placement while Appropriate Spacing is Available

The following responses were about the mainline through traffic volume to place median opening.

- “Limits on expressway and arterials over 3000 ADT”
- “Ratio of mainline to site traffic”

The following factors were the additional considerations of DOTs for median placement:

- “Signal progression”
- “Existing subdividing, topography, creeks/rivers, fire access”
- “Currently ad-hoc, based on need from developers, counties, cities to have full access to state highway”

- "Availability of reasonable access and safety concerns"
- "Speed of highway, classification of highway (we use this to set up rule more than highway ADT), type of approach (public/private), traffic analysis (V/C ratio), availability of alternate access"
- "Whether there was a historical left that the absence of it would cause substantial impairment to the servient parcel. This is considering the caveat for available adequate spacing"
- "We consider public input on raised medians and TWTL's"
- "Gap distance and speed"
- "we use gap analysis"
- "If a full access entrance is proposed at the crossover, then intersection sight distance must be met"
- "Crossroad & driveway locations"
- "Additional adjacent access points, either side-street or connected businesses"
- "Corridor Type (i.e., superstreet)"
- "projected U-turn movements"

Question 3: *Does your agency have any preference regarding full median openings versus directional median openings?*

Among the 29 DOTs who responded to this question, 19 DOTs (65.5%) mentioned that they have preference of a full median opening. 10 DOTs (34.5%) did not have any preference. The following were the open-ended detail responses from the DOTs about the median opening preferences:

- "If spacing is less than ¼ mile in urban areas, then directional opening may be considered"
- "Full openings at future signals roundabouts. Directional/partial openings in between in urban areas for signal relief (turns)"
- "Directional is preferred on high speed rural roadways"
- "Due to concerns of design vehicle accommodation and maintenance we use a lot more full-median openings than directional"
- "Only when advised via a traffic impact study"
- "Our preference is with full median opening (mid-block) as long as there are very limited to no safety concerns otherwise we would consider directional openings when appropriate"
- "Since median opening are very restricted in general directional opening are considered on case by case as determined necessary in order to maintain historical land use"
- "Directional wherever possible"

- “We prefer full median openings where appropriate but use directional medians as a compromise”
- “Full median, but this is only based on tradition”
- “Typically, full access is allowed to comply with driver expectation. Right-in/right-out is also permitted, however 1/4 and 3/4 accesses are typically not utilized”
- “Full median openings are only allowed where warrant 1A 100% can be met all other openings shall be restricted”
- “Depends on type/priority of roadway”
- “If volumes are significant, look towards limiting lefts out (3/4 movement)”
- “Depends on geometrics of roadway and projected movements, other access availability”

Question 4: *Please indicate which of the following indirect left-turn treatments are most common in your state.*

Thirty-one DOTs responded to this question. Figure B-6 shows the indirect left-turn treatment types to accommodate U-turn. Figure B-7 shows that signalized/unsignalized intersection U-turn (Type 8) is the most frequently practiced by DOTs (74% of 31 DOTs). Only two DOTs provided loon (Type 6) (i.e., an expanded paved apron opposite to the median crossover to accommodate U-turning vehicles).

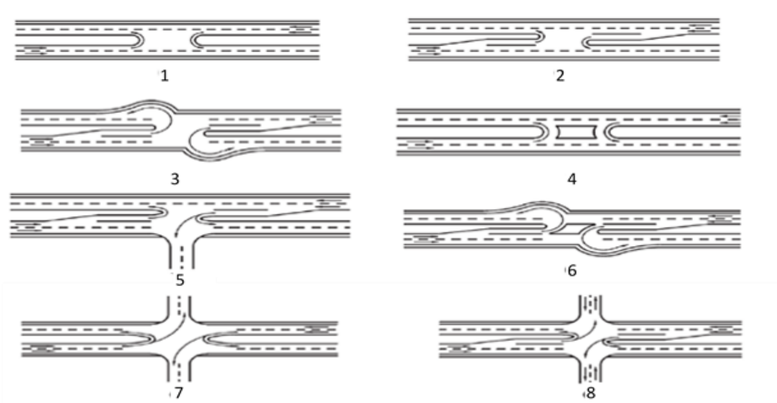


*Figure B-6: Indirect Left-turn Treatment Typ*es [91]

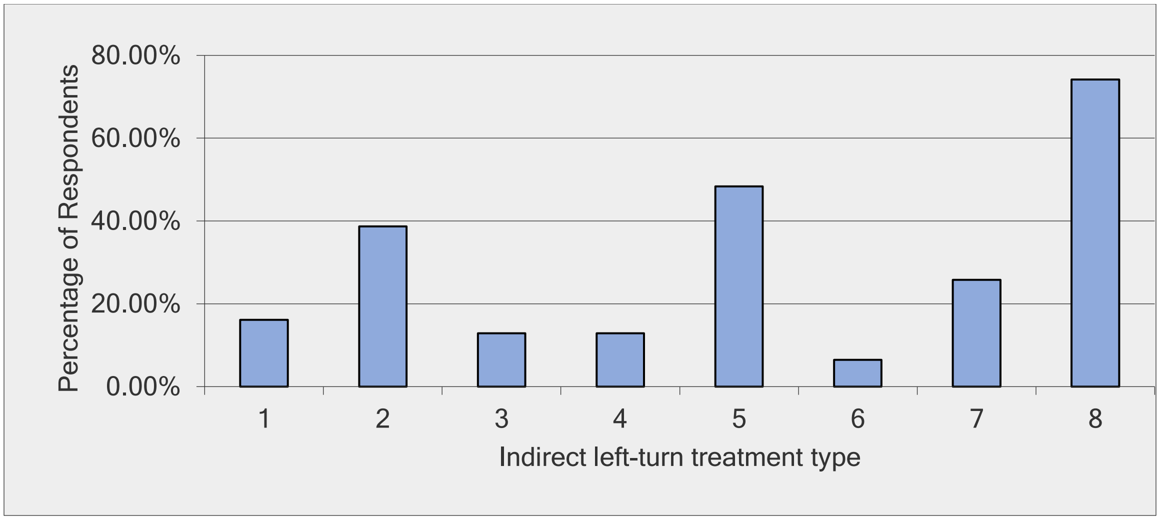


Figure B-7: Indirect Left-turn Practiced by DOTs

Question 5: *What are the challenges of implementing raised medians with full median opening or directional median opening?*

Figure B-8 shows the challenges associated with the raised median implementation based on the DOT responses. Thirty-one DOTs responded to this question. Twenty-seven DOTs (87%) mentioned that opposition from the business owners is the primary challenge for the raised median implementation.

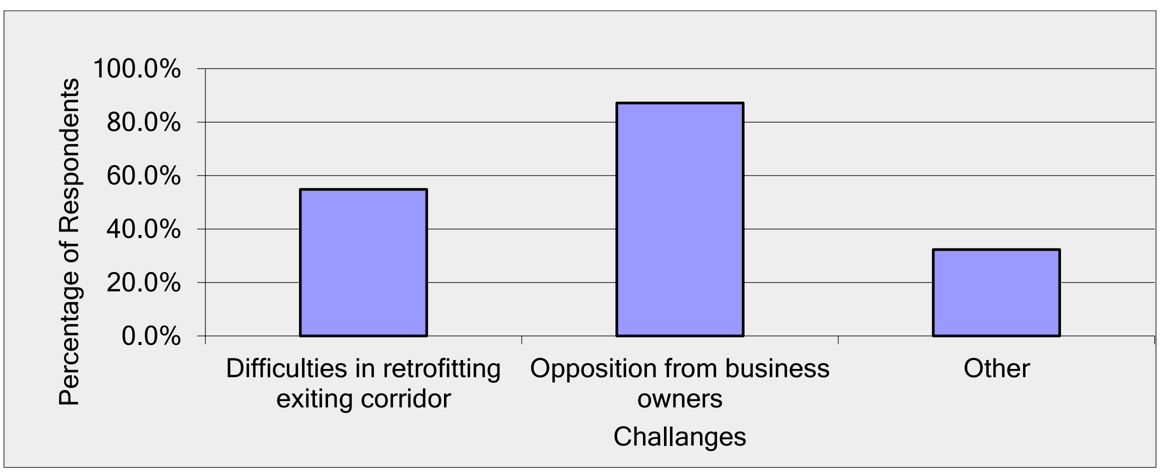


Figure B-8: Challenges with Raised Median Implementation

The following are the responses from several DOTs while identifying the raised median implementation related challenges:

- "Lack of frontage /backage road, internal collectors and poor opposing street alignments"

- "Public opinion seems to overrule empirical science. It comes down to perception = reality regardless of what the statistics imply"
- "Cost"
- "Right of way impacts, excessive cost, safety with higher speed facilities"
- "Political/public opposition"
- "Everyone wants to turn left when and where they want"
- "Funding to convert 5-lane sections. Some 5-lane sections are being converted to raised median divided sections through Safety projects. Community & political support is key"
- "Safety concerns such as sight distance, stacking capacity"

B. 1. 3 Questions about Access Points/Driveways

Question 1: *Under which circumstances would a driveway be modified from fully-open access to some form of restricted access (i.e., right-in/right out, right-in only, right-out only, left-in but no left out, etc.).*

Twenty-seven DOTs responded to this question. 22 DOTs (82%) identified the location of driveway within the intersection influence area as the primary factor as shown in Figure B-9. The second significant factor was whether the driveway left-turn traffic is interfering with the major roadway traffic or not.

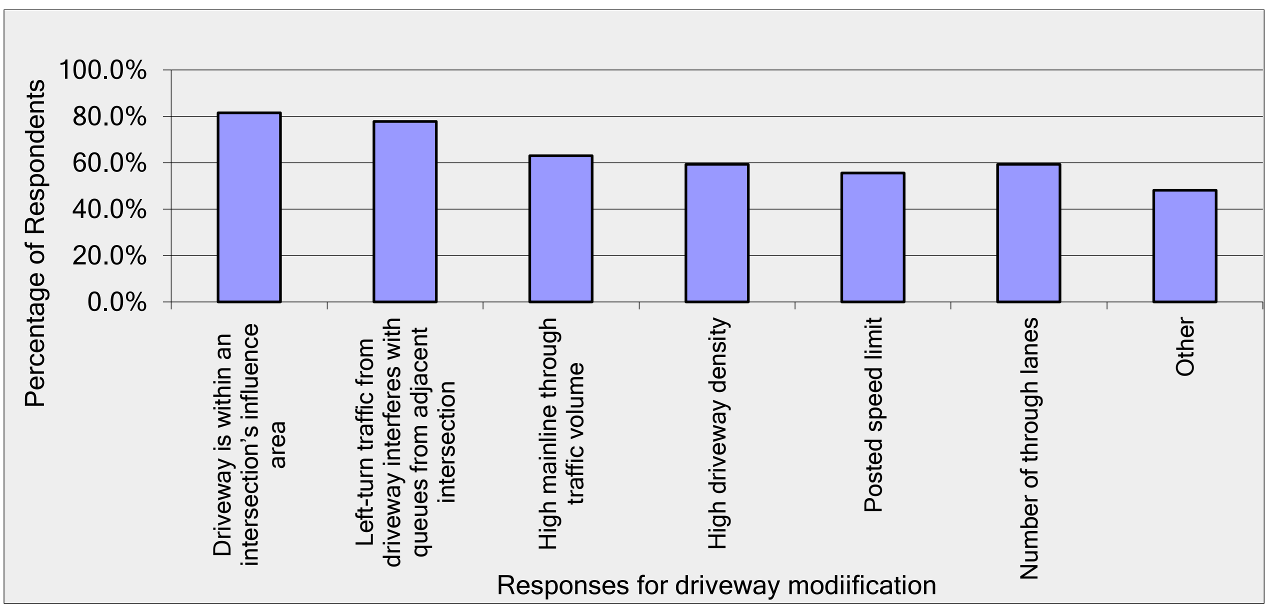


Figure B-9: Factors affecting Driveway Modification

Other factors which influence DOTs to modify any existing driveway from fully-open access to some form of restricted access (i.e., right-in/right out, right-in, right-out, left-in but no left out, etc.) included:

- "High approach ADT. Limited sight distance in one direction. When developments have multiple highway access points we will often look to control movements on the approaches that have less desirable location"
- "Crash history greater than statewide average"
- "We generally don't redesign driveways unless we are buying r/w (especially at interchange areas)"
- "Very hard to change access unless the land is being redeveloped"
- "Any non-compliance with access management regulations results in limiting entrance to right-in/right-out"
- "Crash history"
- "Safety mitigation - improving high crash frequencies"

Question 2: *In instances where the access design of a driveway was modified from fully open to restricted access to improve operational condition, did the condition improve?*

Twenty-seven DOTs provided feedback for this question. Among the 27 DOTs, 23 DOTs (85%) experienced that the operational condition improves after modifying driveways from fully-open to restricted access. Three DOTs did not evaluate the impact yet as shown in Figure B-10.

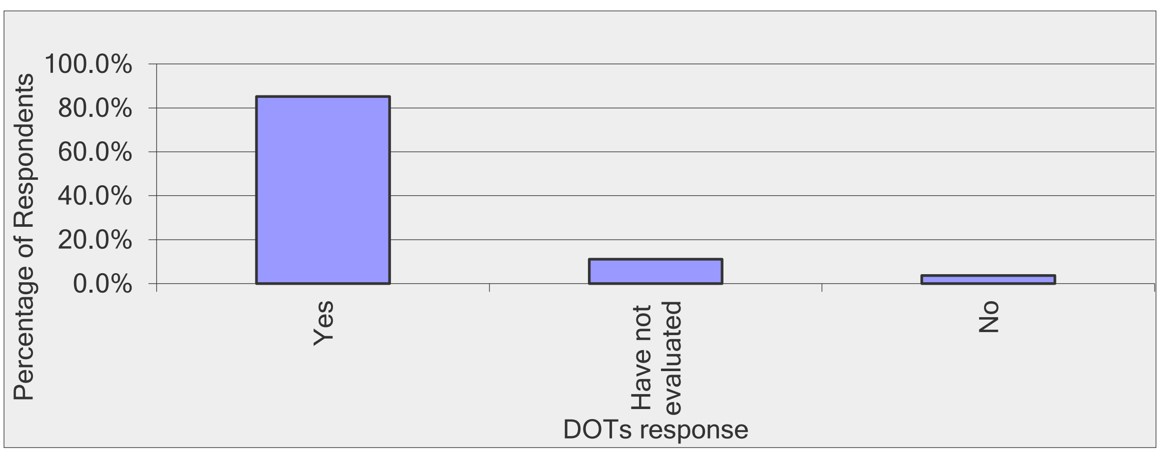


Figure B-10: Operational Improvement observed by DOTs for Restricted Driveway Access

The following is the response from the DOT who has not found any operational condition improvement.

"The condition does not always improve, as it can be very difficult to operationally preclude certain movements, even with geometric re-configuration"

Question 3: *What are the challenges in modifying access of an existing driveway?*

Twenty-seven DOTs replied to this question. As shown in Figure B-11, 26 DOTs (96%) identified the opposition from the business owners as the primary challenge while modifying access of a business. The other challenges identified by the DOTs are as follows:

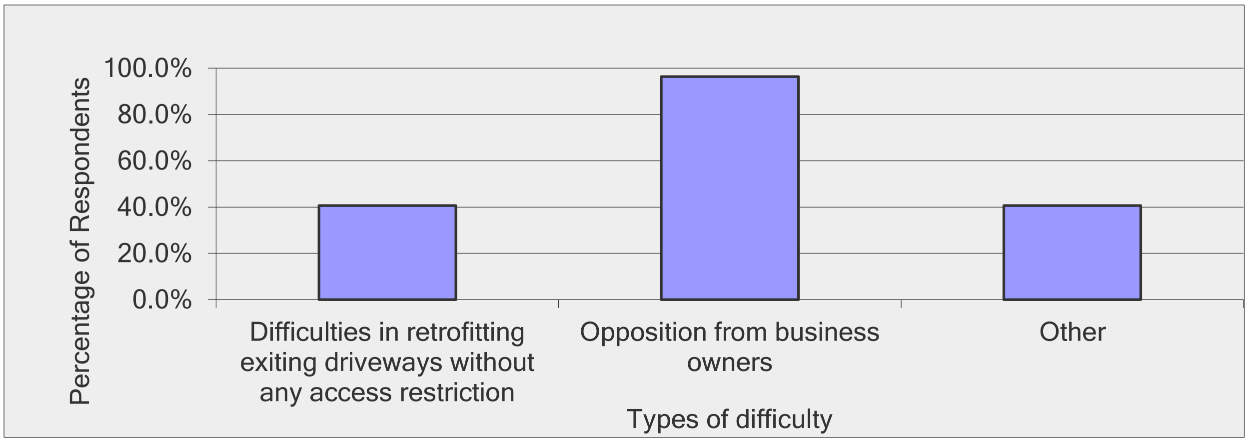


Figure B-11: Challenges in Modifying Access

- "Impacts to owners, lack of alternative access internally"
- "Public opposition"
- "Right-of-way constraints"

B. 1. 4 Questions about Driveway Density

Question 1: *In what circumstances do you consider closing a driveway?*

Survey responses from 26 DOTs were collected for this question. Based on traffic impact study, half of the DOTs closed driveways as shown in Figure B-12. High accident frequency and high mainline through traffic volume were among the other major factors, six DOTs (23%) mention that they never closed any driveway.

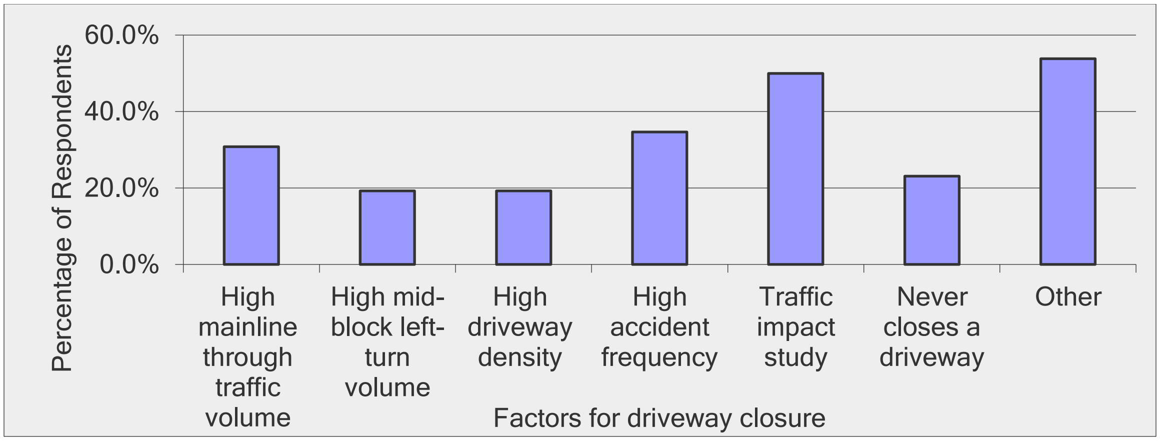


Figure B-12: Factors of Driveway Closure by DOTs

The following are the detail responses from DOTs regarding the mainline through traffic volume:

- "Yes, more than 20,000 ADT"
- "An Expressway is our highest classification of highway and these have large traffic volumes. We do often attempt to close access on these facilities"
- "Yes, no specific threshold"
- "Yes, if alternative access available"

Only one DOT provided a threshold for driveway density. According to this DOT, driveway closure is done when the number of driveways is 5 driveways per side per mile. DOTs provided the following responses about accident frequency while closing driveways:

- "Engineering judgement"
- "Accident number is greater than statewide average"
- "With more than 5 severe crashes per year on average that can be corrected through an improvement"

The following are some other responses by DOTs while closing any driveway:

- "Too close to interchange with heavy volumes"
- "If a driveway lacks sufficient sight distance and the issue cannot be mitigated we would look to close or relocation the driveway. When properties have multiple access, and cannot justify the need we will look to close"
- "One occasion where we close an existing access is if the property finds alternate access to a local street or county road. State law requires direct access to state highways to be granted only if there are no alternate local access serving the subject property"

- “More than one driveway for property”
- “Consider modifications as part of our safety program”
- “depends on location, roadway use, crashes and the number of driveways”
- “redundant access exists”

Question 2: *Does your agency implement ‘driveway closures/consolidation’ in order to decrease the driveway density along roadways?*

Twenty-six DOTs responded to this question. Among the 26 DOTs, 19 DOTs (73%) mentioned that they consolidate driveways. Seven DOTs (27%) did not consolidate driveway. The following reasons for not consolidating driveways were provided by the DOTs:

- “Difficulties in closing and opposition from businesses”
- “If this were done, it would be done as part of a corridor construction project”
- “Approved driveways typically require compensation for access changes. For redevelopments, a new access permit is required, and there is opportunity for consolidation”

Question 3: *What are the perceived effects of the driveway consolidation?*

Figure B-13 shows the perceived effects of driveway consolidation. It shows that 15 DOTs (60%) observed reduced mainline traffic travel time. Some other DOTs also observed improved operational condition in minor road (12%).

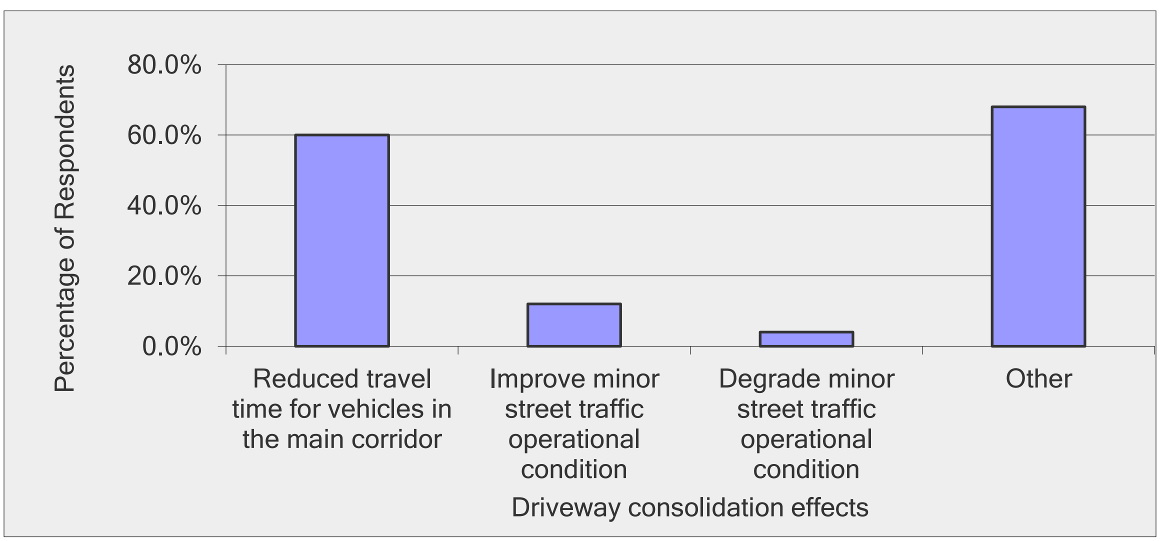


Figure B-13: Effects of Driveway Consolidation

The following effects were observed by DOTs:

- "Improved mainline safety, improved mainline traffic control and minimized/ efficient use of devices"
- "Consolidation of access makes it more difficult for residence, employees and customers to get to a home or business"
- "Consideration for less conflict points will improve accident history and LOS"
- "Decreased crash rate"
- "Not worth the expense and trouble, especially if we can control left turns with medians"
- "Fewer crashes"
- "Reduction in mainline rear-end crashes"
- "Improved safety"
- "By reducing driveways would tend to increase safety and operations overall in the corridor"

Question 4: *What are the typical challenges in implementing shared driveways?*

Twenty-six states answered this question. Among them, 24 states (92%) identified that convincing business owners is the most challenging part while implementing shared traffic access as shown in Figure B-14. Nine DOTs identified the following challenges which they face for implementing shared access.

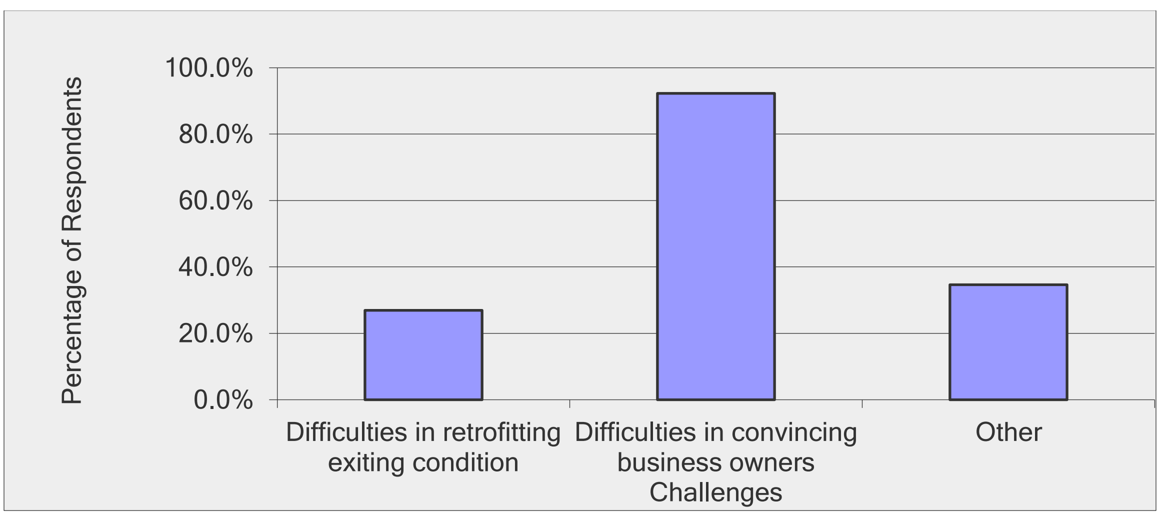


Figure B-14: Challenges for Implementing Shared Access Points

- "Owners of all types may not get along or maintain equitably"
- "Residential owners that do not want to share access or even the access apron"
- "Right of way needs associated with a driveway improvement"
- "Forcing easements between property owners"

- “Right-of-way negotiations, individual property owners with different uses for same access point”

B. 1. 5 Questions about Corner Clearance

Question 1: *Does your agency closes driveways when they are located within the minimum corner clearance distance, according to your policy, from an intersection?*

Twenty-six DOTs provided feedback for this question. Among them, 14 DOTs (54%) closed driveways when they were within the corner clearance distance, according to their own policy. The other 12 DOTs (46%) did not close driveways after the corridor development while these driveways are within the minimum corner clearance distance. The following are the detail responses from these 12 DOTs who did not close driveways within corner clearance:

- “We currently do not have an access policy that governs roadway design”
- “There are possibly hundreds of non-conforming corners across the state. We do not address this type of problem on a proactive basis, rather they are addressed on a project by project basis”
- “We have spacing standards to other driveways. However, deviations are often approved if there are not reasonable alternatives”
- “We don't have a policy on corner clearance”
- “Expensive and difficulty”
- “When the driveways were installed. No policy, so some are grandfathered in”
- “We try to adhere to a strict 'limits of no access' prior to driveway installation”
- “We may move the driveway if there is a crash or operational issue but would need to be an overall construction project”
- “Approved driveways typically require compensation for access changes. For redevelopments, a new access permit is required, and there is opportunity for consolidation”
- “We only restricting a driveway access when it has a safety issue”

Question 2: *What is your agency’s policy for new constructions that have limited corner clearance?*

Twenty-six DOTs responded to this question. As shown in Figure B-15, 15 DOTs (58%) mentioned that they did not allow driveways for new construction if these driveways were within the corner clearance distance, according to the state policy. Ten states (39%) allowed driveways if the developers provided sufficient access waivers. Ten DOTs provided other detail responses for implementing driveways in corner clearance distance, which are explained here:

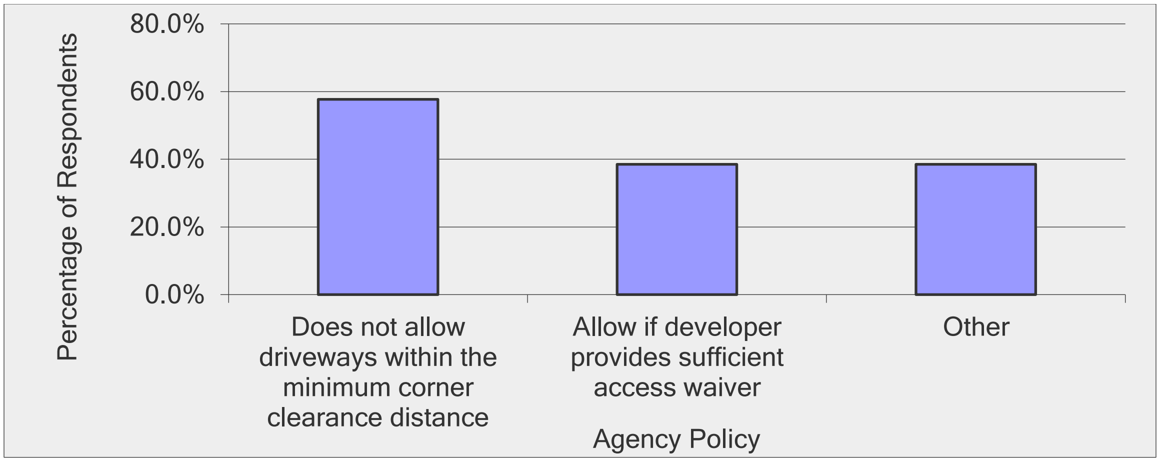


Figure B-15: Agency's Policy for New Constructions Having Limited Corner Clearance

- "We have an exceptions process for permitting new driveways that do not meet state regulations"
- "We will work to provide the safest point of access"
- "We don't have a policy on corner clearance"
- "We do have a design waver process but are very strict on keeping to our access code which does not allow it"
- "Permitted if no alternative access is available"
- "If that is the only way to access property we try and make it work"
- "Queue analysis"
- "Do not allow unless there are no other reasonable options for access.   (We must legally provide access to all properties unless we've purchased access rights.)"

Question 3: *What are the thresholds of ADT, driveway volume, etc. that would allow a driveway to remain open even though it is within an intersection's influence area?*

Twenty-three DOTs responded to this question. As shown in Figure B-16, 11 DOTs (48%) did not have any threshold to allow their driveways, situated in intersection influence area. Four DOTs (17%) allowed the driveways to remain open if the driveway volume is low. The responses from these four states as follows:

- "Low driveway volume < 10 vph less of a concern"
- "Low drives volumes, e.g. house, low speeds, it seems practical based on cost to cure and risk"
- "Driveway volume 500 per day"

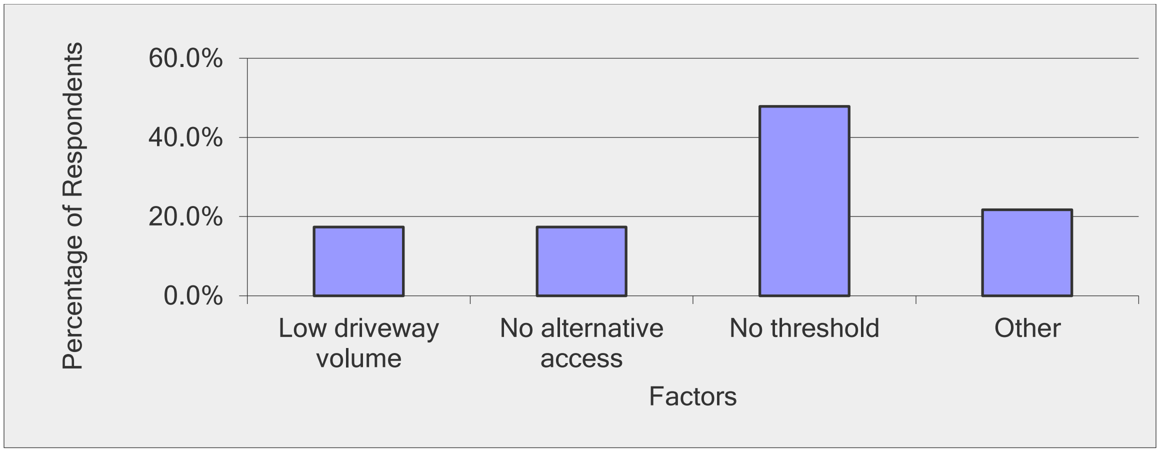


Figure B-16: Factors to Keep Driveways Open while in Intersection's Influence Area

Five DOTs (22%) mentioned other considerations for closing driveways in intersection influence areas, which are given below:

- "This is not defined by administrative rule; however, the Department maintains the right to close accesses for cause. In some instances, this can lead into expensive eminent domain litigation"
- "Business and political influence"
- "We do hesitate on bringing any historical access to compliance unless they are applying for improvement or a land use change"
- "Discretion of the respective District"

Question 4: *What are the challenges in restricting driveways within the minimum corner clearance distance of an intersection?*

Twenty-six DOTs answered this question. As observed in Figure B-17, 23 DOTs (89%) acknowledged that restricting driveways in small isolated corner lots are difficult. The main reasons for not restricting driveways in corner lots were: a) if no alternative access is available, b) site geometry and topology, and c) expenses. 22 states (85%) faced significant challenges from business owners in restricting driveway access at corner lots. Another challenge was the lack of corner clearance policy. One DOT did not have any policy regarding corner clearance.

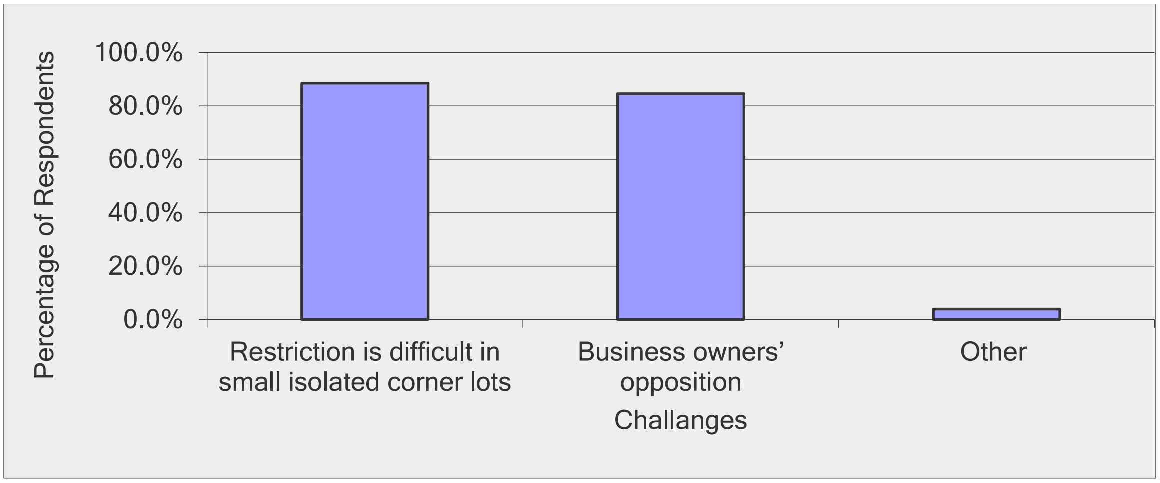


Figure B-17: Challenges in Restricting Driveways in Corner Clearance Distance

B. 1. 6 Questions about Intersection Auxiliary Lanes

Question 1: *Are right-turn deceleration/acceleration lanes used at non-signalized driveways?*

Twenty-six DOTs provided response for this question. Among them, 25 states (96%) used right-turn deceleration/acceleration lane for an intersection.

Question 2: *What roadway/traffic conditions necessitate the use of right-turn deceleration/acceleration lane at non-signalized driveways?*

Twenty-three DOTs responded to this question. Fourteen DOTs (65%) identified high driveway traffic volume necessitates the use of right-turn deceleration/acceleration lane. Ten DOTs (57%) identified high mainline through traffic and four DOTs (43.5%) identified average queue length as the factors to implement right-turn lane as shown in Figure B-18.

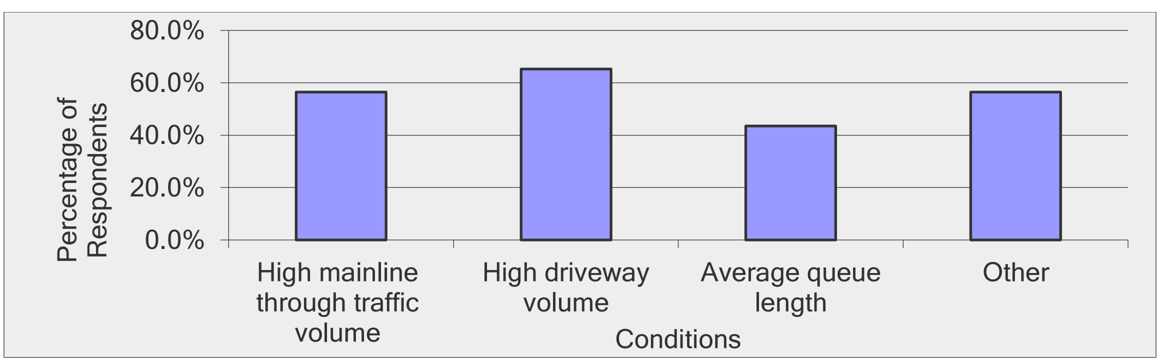


Figure B-18: Conditions for Right-Turn Deceleration/Acceleration Lane for Non-Signalized Intersection

The following are the detail responses from states about the mainline through traffic volume:

- "NCHRP 279 charts"
- "DDHV varies from 200 vph and more"
- "With right turning traffic greater than 300 vehicles per hour"
- "Chart in Design Manual"
- "Engineering judgement"
- "Turn lane warrants"

The following detail responses were collected from states about the driveway traffic volume:

- "40 vehicles per hour"
- "Right turn acceleration when volume greater 50 VPH & right turn deceleration when volume is greater than 25 VPH"
- "Greater than 50 vehicles per day, but as few as 6 right-turning vehicles per hour"
- "Volumes to warrant are based on speeds and volumes of adjacent lane"
- "Always when more than 150 right turning vehicles per hour"
- "Chart in Design Manual"
- "Engineering judgement"
- "Turn lane warrants"
- "Approximately 100 right-turning vehicles per hour"

The following are the other considerations by state DOTs for right turning acceleration/deceleration lane for non-signalized driveways as per the state DOT responses:

- "Based on traffic study"
- "Guidance under development"
- "National guidelines for the use of deceleration/acceleration lanes"
- "The need is based on crash problems and sight distance"
- "Based on operational Analysis"
- "Must meet warrants based on number of lanes, right turn volume and total volume"

Question 3: *26.What are the challenges in installing auxiliary lanes?*

Twenty-five DOTs responded to this question. Among the 25 DOTs, 24 DOTs mentioned that the right-of-way restriction was the primary challenge for implementing auxiliary lanes as shown in Figure B-19. Only one state responded the following:

'We don't use auxiliary lanes inside urban areas. They are only used on the more high-speed facilities statewide.'

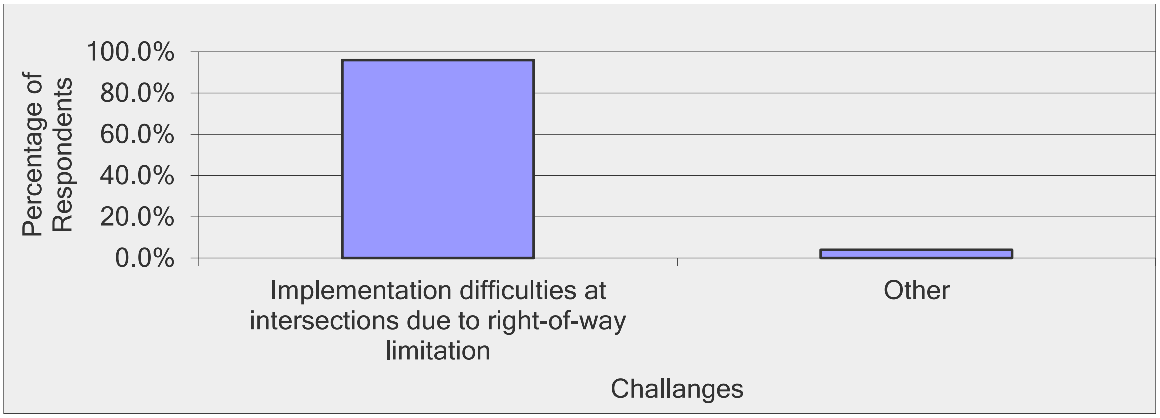


Figure B-19: Challenges in Installing Auxiliary Lanes

B. 2 Phone Interview Results from State Transportation Agencies in the U.S.

Question 1: *Does your agency have different guiding documents/handbooks/manuals governing access management for i) new roadway construction and ii) retrofit projects?*

This question was asked to identify if states have different guidelines for any new roadway construction, and for retrofitting any existing corridor to incorporate different access management strategies. Among 18 states, 15 states (83%) did not have different guidelines for these two different types of projects. Some of these 15 states mentioned they try their best to adhere to the access management related guidelines (e.g., driveway spacing, median opening) while retrofitting any urban arterials. Only three states (17%) mentioned that they have different access management guidelines for new roadway construction project and retrofitting existing corridor project.

Question 2: *If the answer of Question 1 is 'no', do you have any plan to incorporate guidelines for retrofitting existing corridors?*

Among the 15 states that do not have different guidelines for new construction vs. retrofitting corridors, seven states responded to this question. Six states (86%) mentioned that they do not have plan to develop guidelines for retrofitting corridor projects. One state responded, "standards are not strictly enforced to retrofit corridors". Only one state expressed the willingness to develop access management guidelines for retrofitting projects.

Question 3: *When does your agency attempt to retrofit corridors to incorporate any access management strategy?*

Figure B-20 shows the agency responses for this question. It shows that nine states (50%) consider both the safety and operational improvement requirements to select any access management project. Seven states (39%) mentioned their primary concern is to improve the corridor safety conditions.

Only two states mentioned that if they can identify any corridor which is non-compliant with the access management guidelines, they will retrofit the corridors.

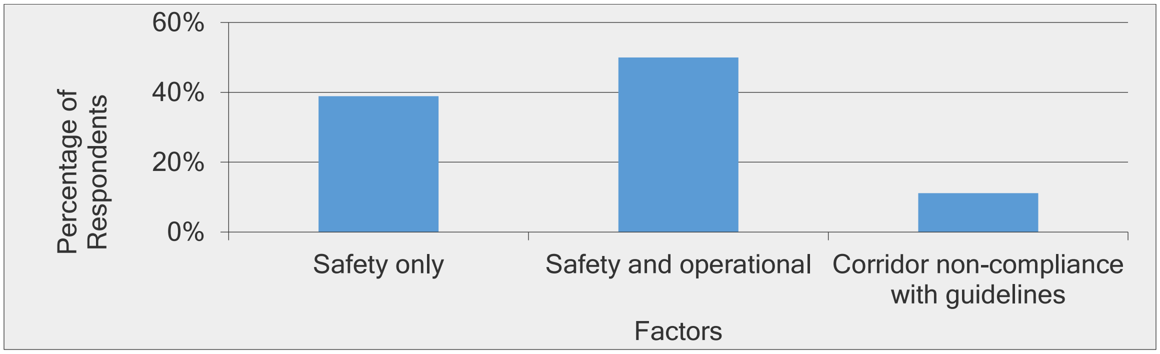


Figure B-20: Factors Affecting Agency Decision to Incorporate Access Management Strategy

Question 4: *How is a decision made about closing an access point/driveway?*

Sixteen states replied to this question. Some states consider multiple factors before recommending closing any business access. As observed in Figure B-21, 15 states (94%) mentioned that they consider safety improvement to close driveways. Six DOTs (38%) mentioned that they want to improve operational condition of a corridor by limiting access. One state mentioned they check the overall driveway spacing along the corridor. If the driveway spacing is violating the recommended spacing from the manual, they would close the driveway. Another consideration for driveway closure is the change of business ownership. If the business type changes with time, and there is no need to have direct access from the highway (considering there is alternative access to the business) the state would close the driveway.

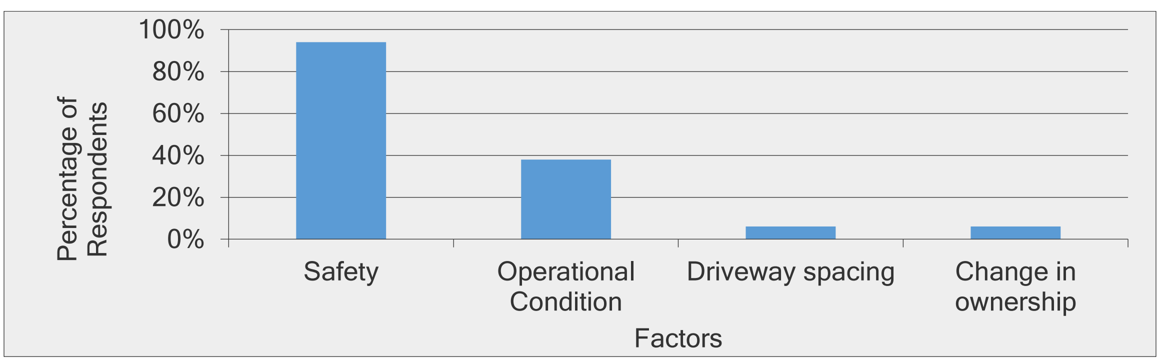


Figure B-21: Factors Affecting Access Closure Decisions

Question 6: *Are frontage roads or service roads encouraged or included in the agency's guidelines for new construction to provide access rather than driveways for each individual business along a roadway?*

Seventeen states responded to this question. The motivation behind the question was to identify whether states encourage frontage roads in their states or not. Fifteen states (88%) mentioned that they encourage frontage road, but they are not always required. Based on their discussion is was found that frontage roads are mostly encouraged in rural highways, where there is sufficient rights-of-ways available. Two states (12%) mentioned that they do not encourage frontage roads in their states. The reason for not providing frontage road is that states has law to provide access to each business, which often restricts their freedom to implement frontage road by limiting direct access from highway to each business.

Question 7: *Can business make appeals to have their driveway remain open?*

Eighteen states responded to this question. Among them, 14 states (78%) mentioned the business owners can make appeal once the decision of closing their highway access is made. They can make appeal to their respective district engineers, access management appeal committee or they can appeal to district court. Only one state mentioned that the business owners do not persist once the decision is made about closing their driveway. Three states (17%) mentioned than business owners cannot make an appeal against the access closure decision.

Question 10: *Did your state DOT face any lawsuit from business owners after implementing any access management strategy?*

Among the 18 states, 15 states (83%) have faced lawsuits from business owners after implementing access management strategy. Business owners fear the corridor-wide access modification, and believe that modifying, relocating or closing their highway access would cause potential damage to their business. Among the 15 states, one state mentioned they faced lawsuits pretty frequently whereas three states mentioned they have experienced very few lawsuits. This shows the business owners' conviction in opposition varies from one state to another. Only three states (17%) mentioned that they did not face any lawsuits from the business.

Question 11: *How has your agency dealt with resistance from business owners on construction or modification of access to their businesses?*

States use the following ways to convince the business owners about any access management related construction or modification tasks:

- Five DOTs, (28%) gather findings from previous studies to convince business owners and try to communicate the project benefits based on the earlier studies

- Four DOTs (22%) mentioned that they district staffs work closely with locality and businesses to avoid any possible conflicts.
- Two DOTs (11%) mentioned that they usually pay for the right-of-way acquisition and damages to the business. One of these two states mentioned that if needed, they will go to court to solve the issue.

Question 12: *What type of spot improvements are most common for access management?*

Figure B-22 shows the responses from 18 states. It shows that the most common spot improvement projects are: 1) driveway consolidation and 2) add median, median opening or closure. Eight DOTs (44%) mentioned they implement these two spot improvement projects pretty often. Six DOTs (33%) mentioned that they often implement left-turn restriction and channelization of driveways. Two DOTs (11%) often add turn lane for the driveways. Only one DOT mentioned that they close driveway/traffic access points often.

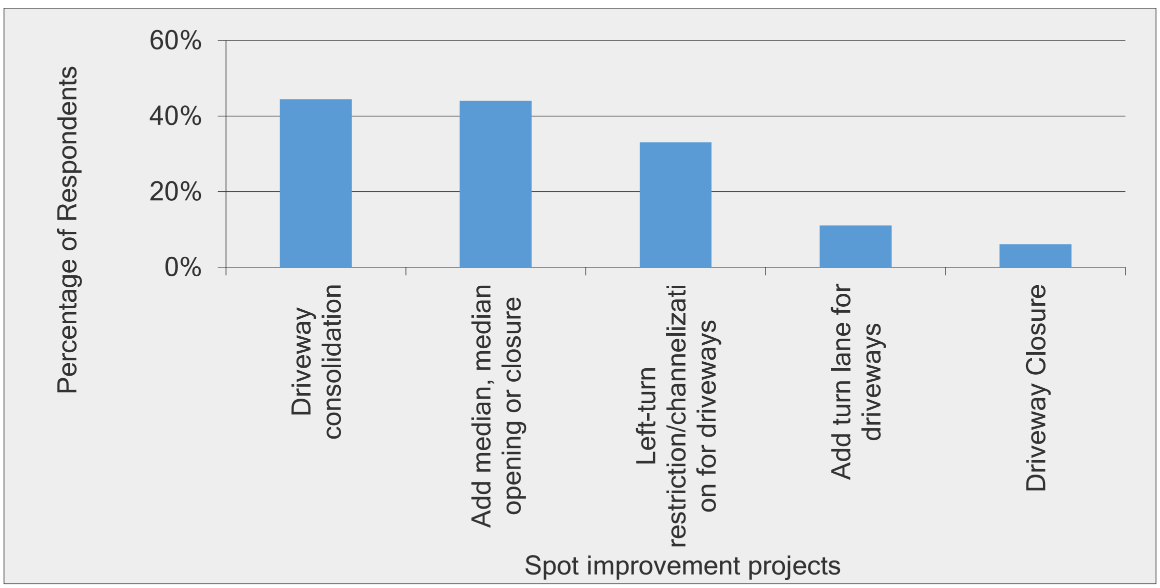


Figure B-22: Common Spot Improvement Projects

Question 13: *Did your agency perform a study or fund a study to examine the economic impact of access management strategies?*

Among the 18 states participated that in the phone interview, seven states studied the economic impact of access management strategies. The majority of the states (61%) did not evaluate the economic impact of access management.

Question 15: *If yes to question 13, what were the key findings of the study?*

The key findings from the economic analysis from the states are:

- Medians have no impact except on "impulse" businesses
- Access management strategy showed benefits for property owners, it increases in customers
- No significant difference was perceived for businesses after implementing the access management strategies.

Question 16: *If yes to question 13, has your agency change your practice/policy/design guidelines as a result of the study's findings?*

Only three states (17%) have updated their access management policy/design guidelines based on the findings from the economic study.

Question 17: *If no to question 13, what are the reasons for not conducting the economic evaluation?*

Figure B-23 shows the state responses to this question. Five states (45%) mentioned that they do not study economic evaluation of access management because they believe safety and operation impact assessment are more important. Four states (36%) identified the funding scarcity as the primary reason. Two states (18%) mentioned that other states and national-level studies have studied the economic evaluation of access management. They use those findings to convince business owners while implementing any access management project.

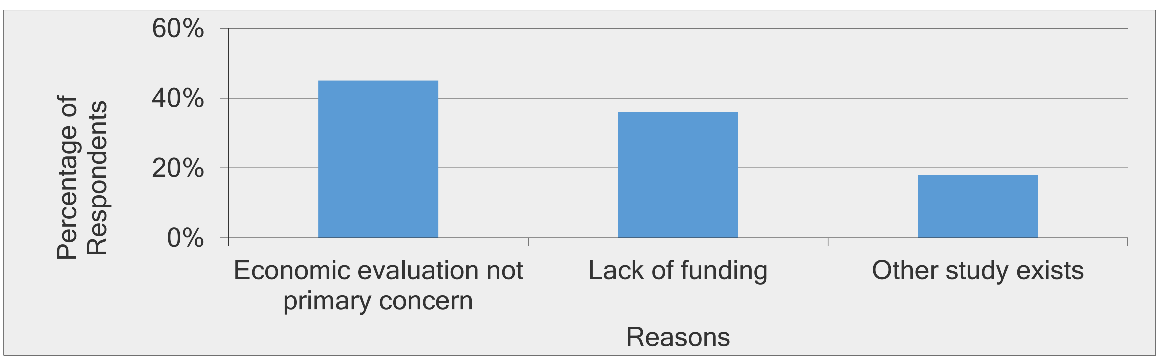


Figure B-23: Reasons for not Conducting Economic Evaluation

Question 18: *Do you have any suggestions for addressing the following specific issue in raised median design for urban arterials:*

The requirements for the deceleration and storage of left-turning vehicles may exceed the available length between two intersections. How do you deal with the median treatment under this circumstance? Please explain: ____

Twelve states answered this question. Some states DOT personnel mentioned multiple ways to handle the left-turning vehicle. As shown in *Figure B-24*, seven states (64%) mentioned they would restrict left-turn vehicles in the intersection and allow the left-turn and U-turn in the next intersections. Five states (45%) mentioned that they would change the road geometry to accommodate the turning vehicles. These states mentioned they would reduce taper lane and deceleration lane, lengthen left-turn lane, widen lane and use Jughandle or roundabout. One state mentioned that they would close the driveways to reduce left-turn vehicles.

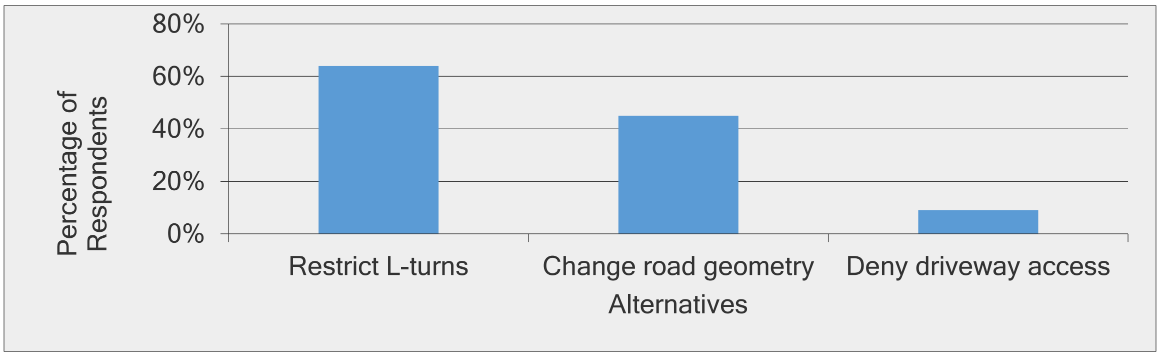


Figure B-24: Alternatives suggested by States to Accommodate Traffic

APPENDIX C SELECTED CORRIDORS AND ACCESS CONTROL STRATEGIES

Figure C-1: S.C. 146 Greenville Woodruff Road

Figure C-2: U.S. 176 Richland (Broad River Road) Corridor

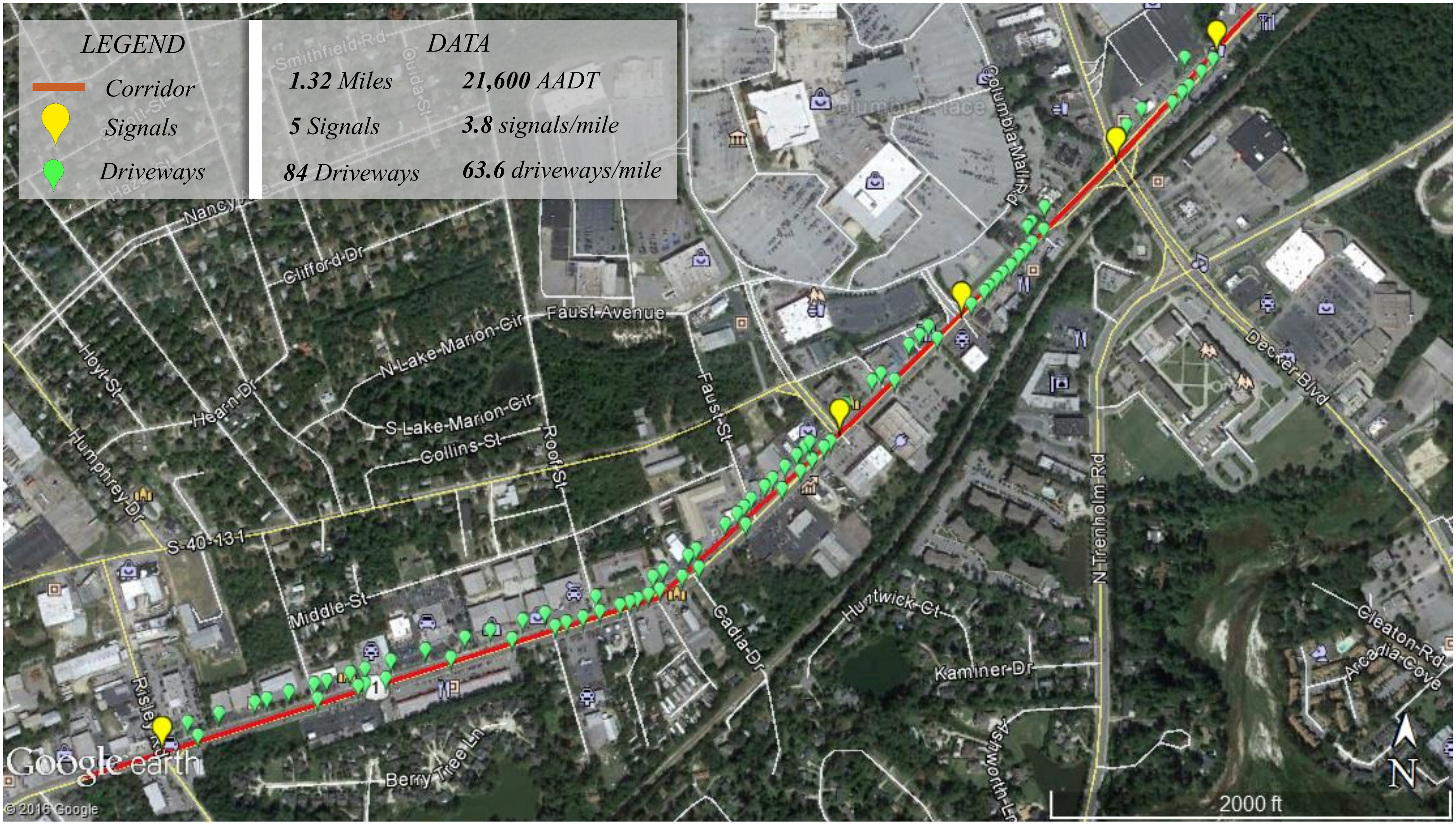


Figure C-3: U.S. 1 Richland #1 (Two Notch Road) Corridor

Figure C-4: U.S. 29 Greenville #1 (Wade Hampton Blvd) Corridor

Figure C-5: U.S. 29 Greenville #2 (Wade Hampton Blvd) Corridor

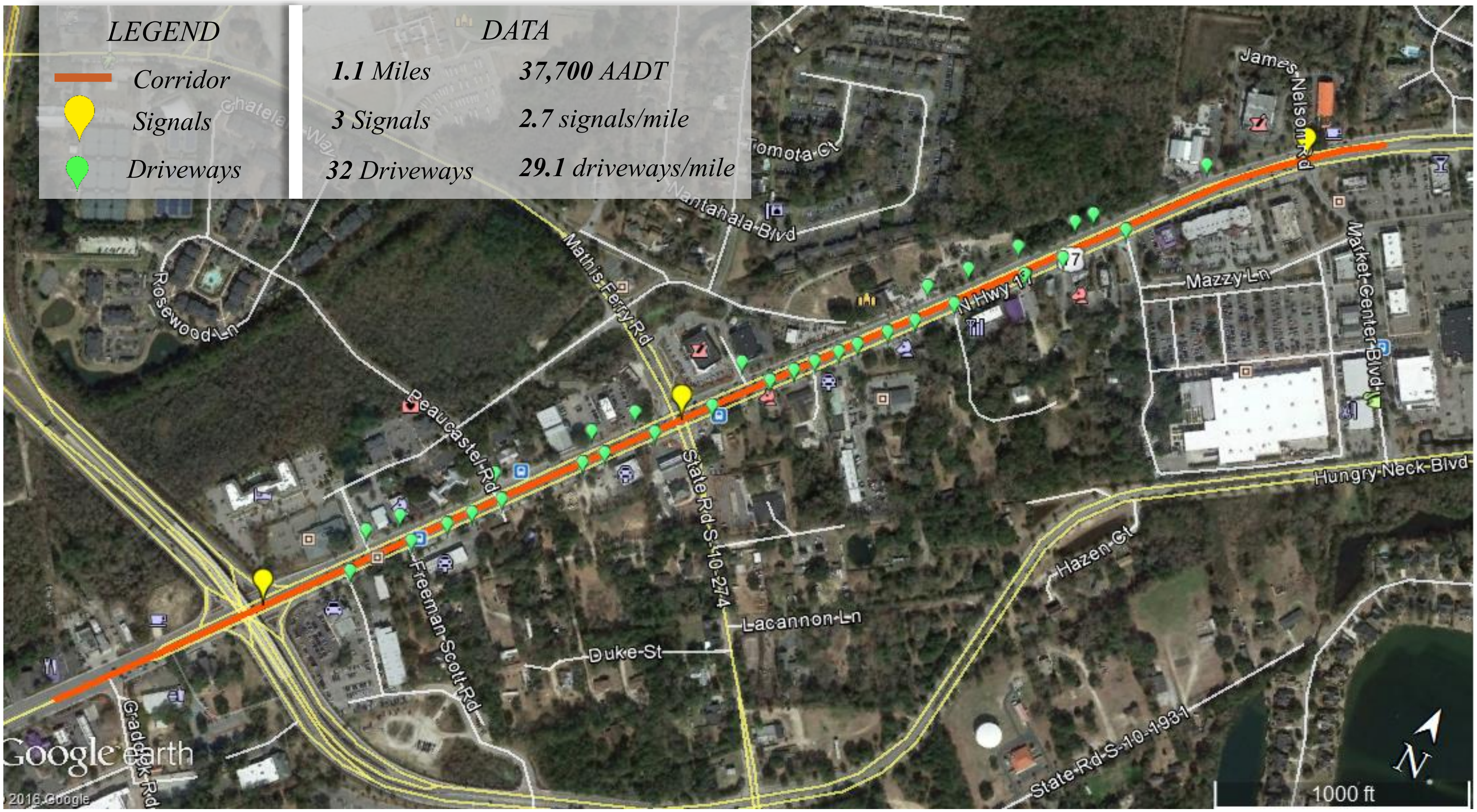


Figure C-6: U.S. 17 Charleston Corridor

Figure C-7: U.S. 1 Richland #2 (Two Notch) Corridor

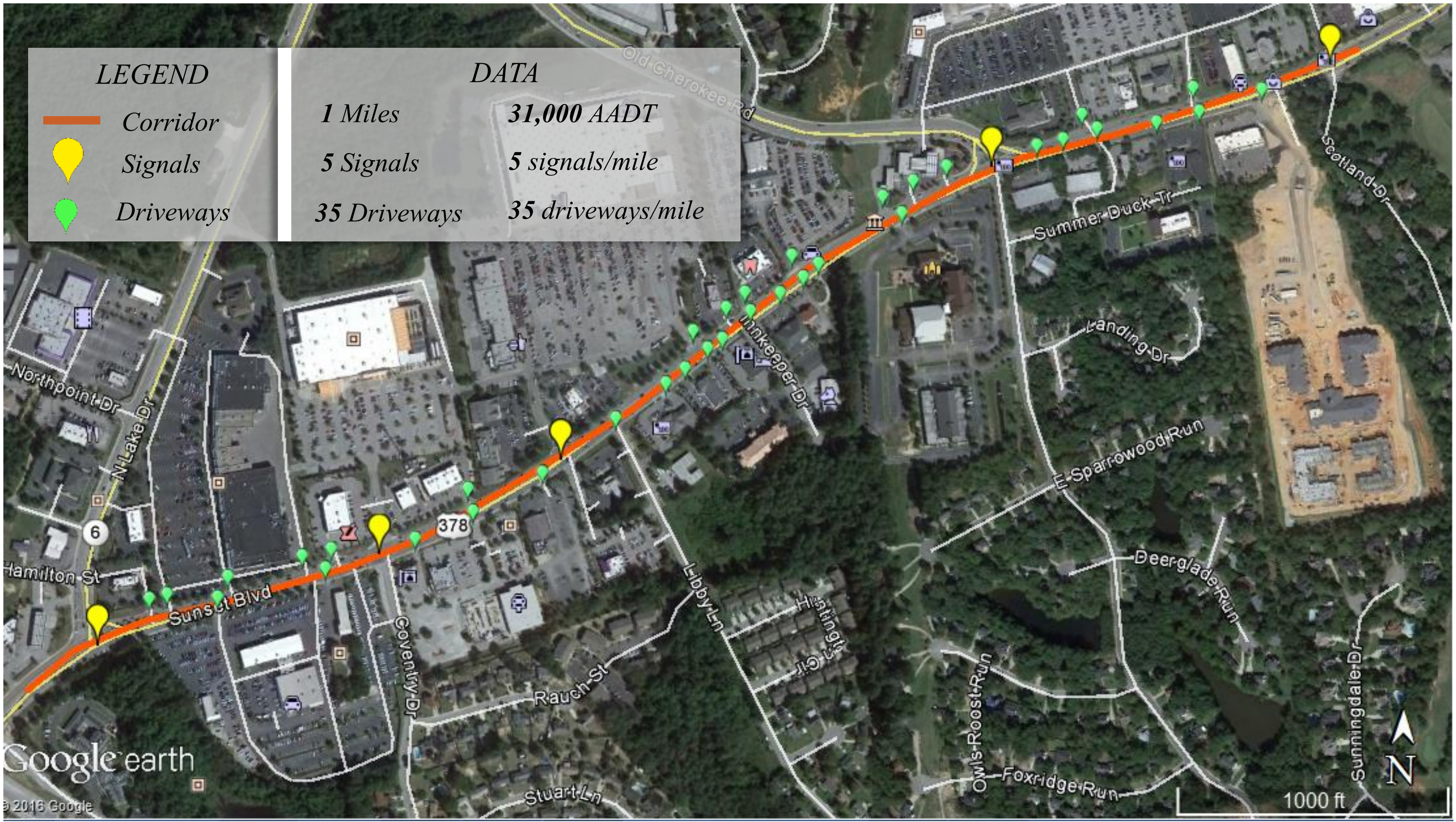


Figure C-8: U.S. 378 Lexington #1 (Sunset Blvd) Corridor

Figure C-9: U.S. 378 Lexington #2 (West Main Street) Corridor

Figure C-10 : U.S. 76 Florence (W Palmetto St) Corridor

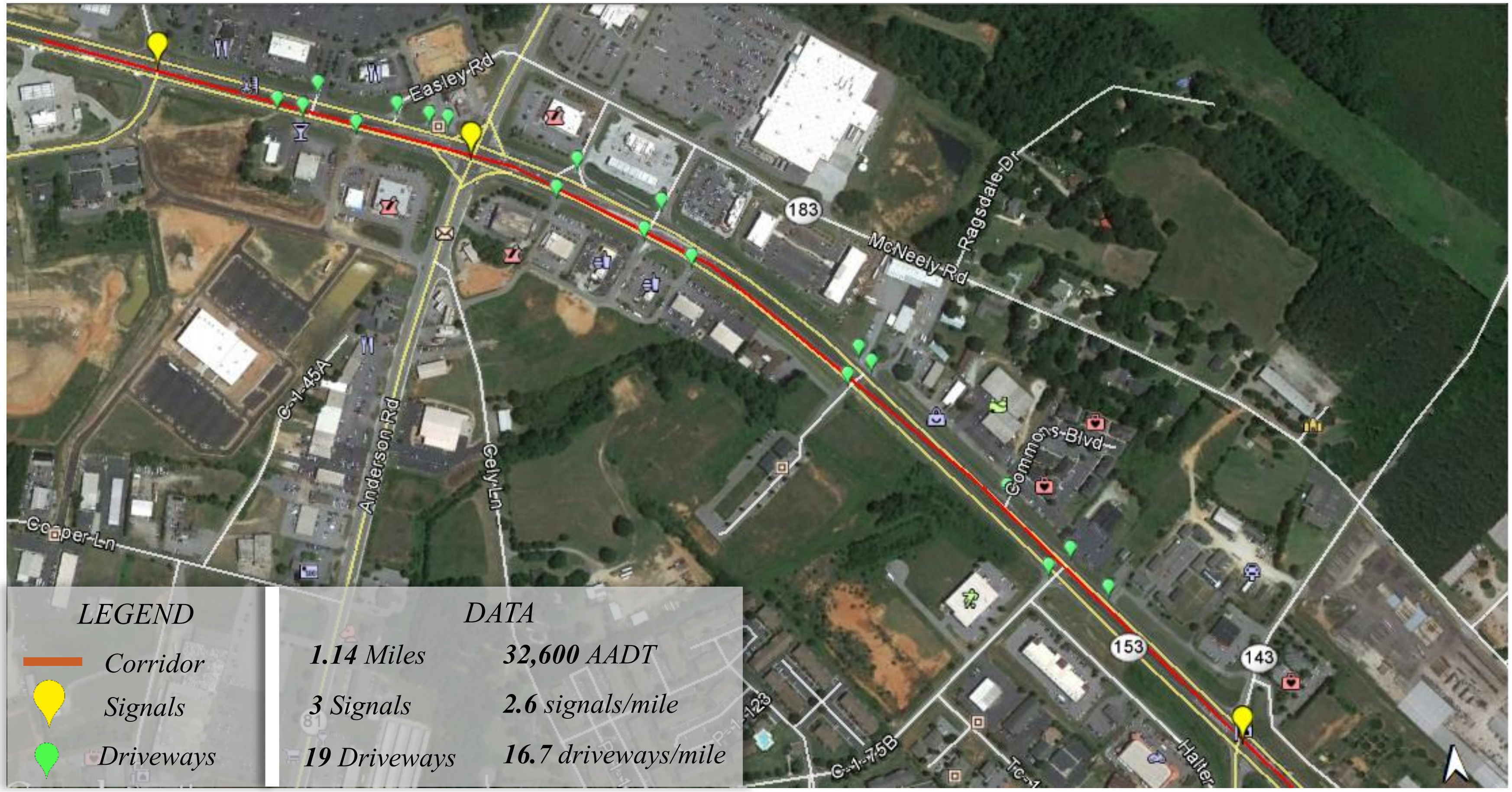
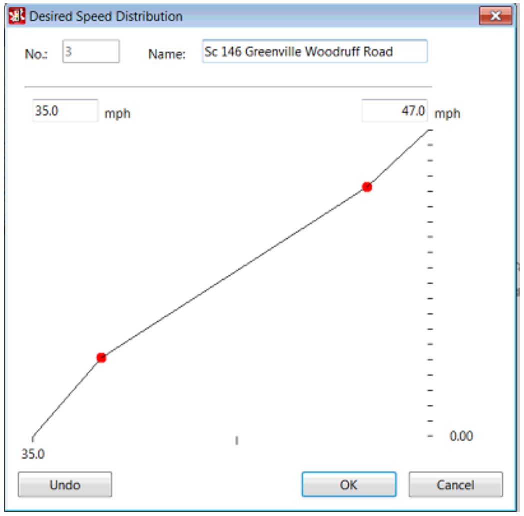
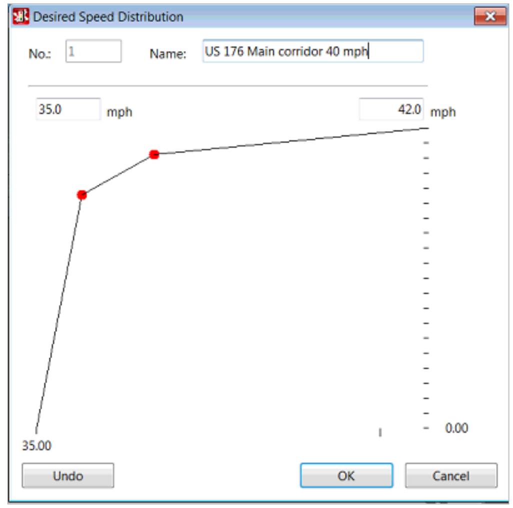


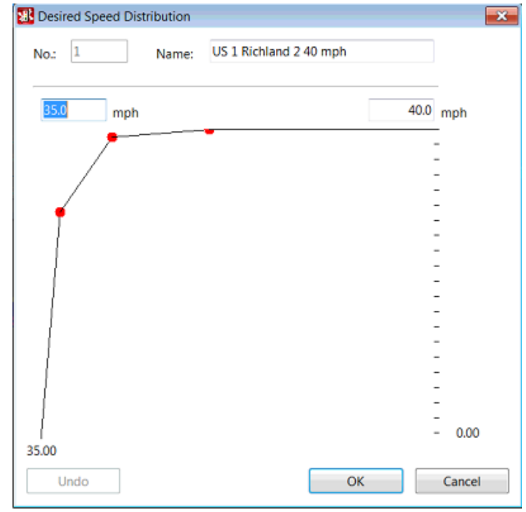
Figure C-11: S.C. 153 Powdersville Corridor



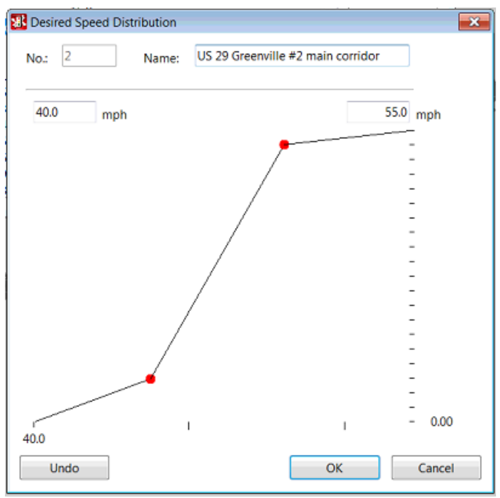
(a) *Speed Distribution for SC 146 Greenville*



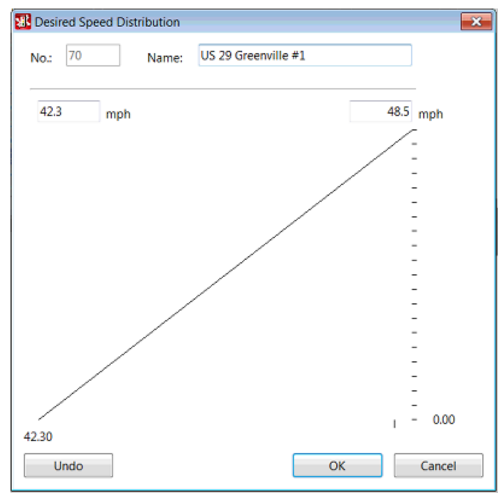
(b) *Speed Distribution for US 176 Richland*



(c) *Speed Distribution for US 1 Richland #1*

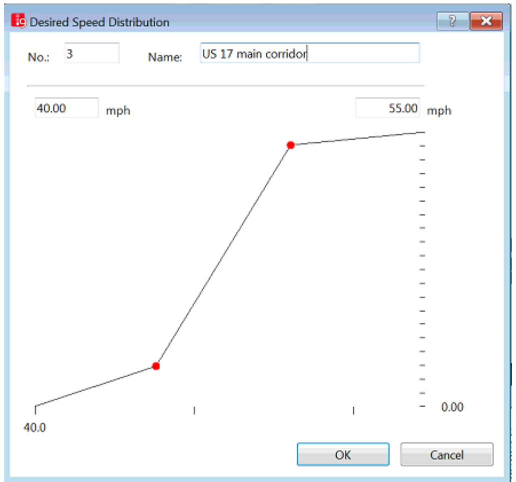


(d) *Speed Distribution for US 29 Greenville #1*

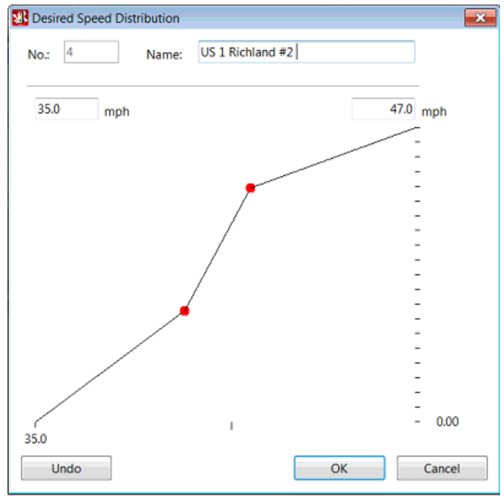


(e) *Speed Distribution for US 29 Greenville #2*

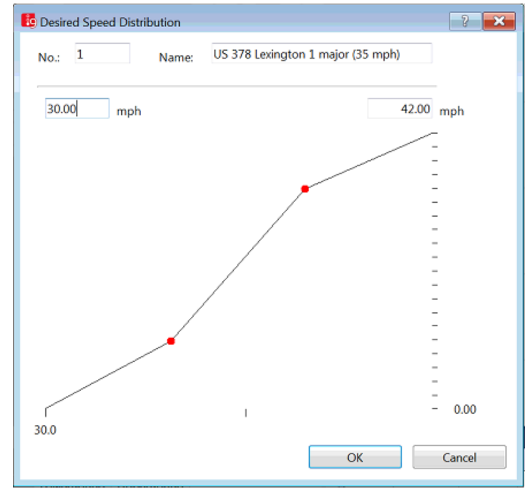
Figure C-12: Desired Speed Distribution on Corridors selected for Operational Analysis (Source: VISSIM)



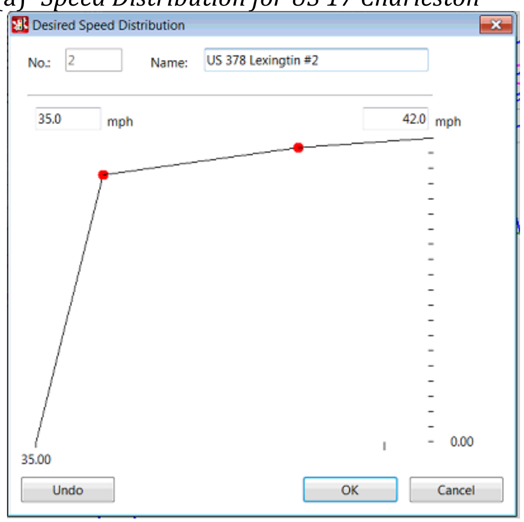
(a) *Speed Distribution for US 17 Charleston*



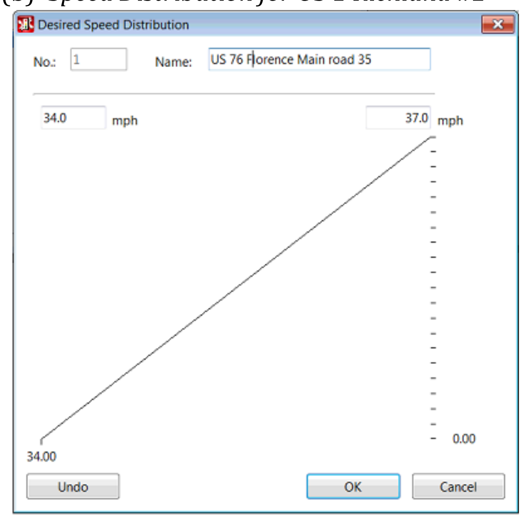
(b) *Speed Distribution for US 1 Richland #2*



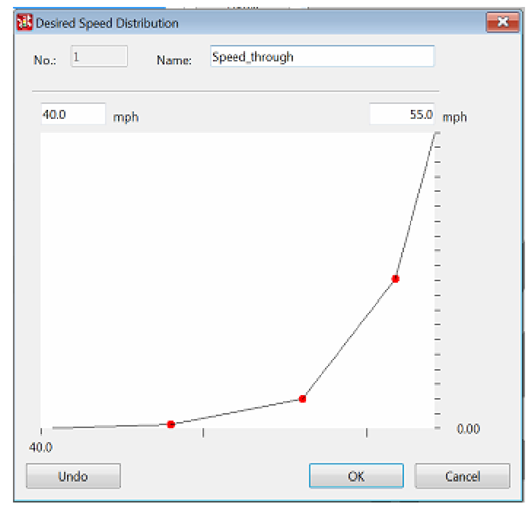
(c) *Speed Distribution for US 378 Lexington #1*



(d) *Speed Distribution for US 378 Lexington #2*



(e) Speed Distribution for US 52 Florence



(f) Speed Distribution for SC 153 Powdersville

Figure C-13: Desired Speed Distribution on Corridors Selected for Operational and Economic Analysis (Source: VISSIM)

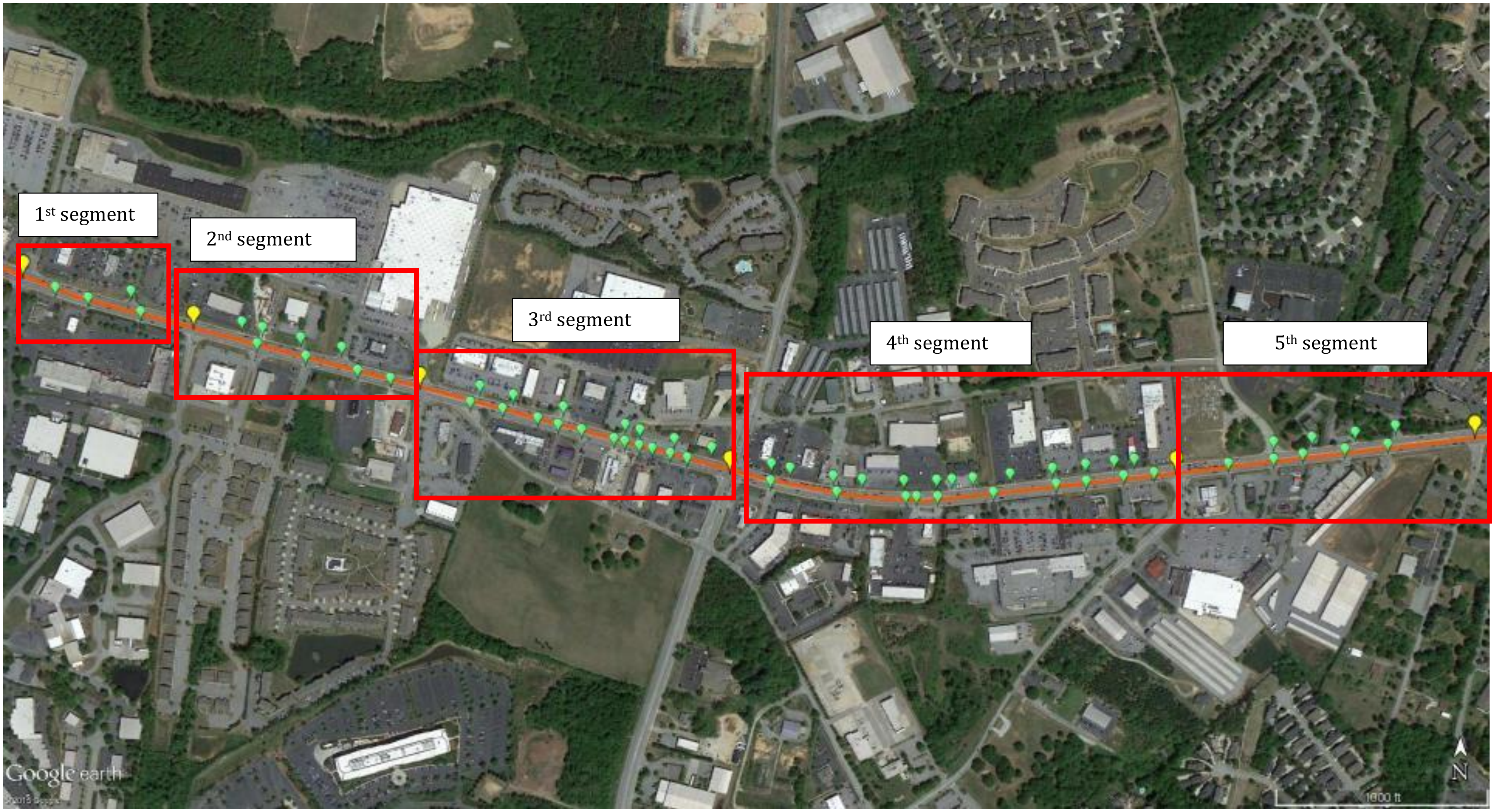


Figure C-14: Consolidation of Driveways along S.C. 146 Greenville

Figure C-15: Consolidation of Driveways along S.C. 146 Greenville, 1st segment

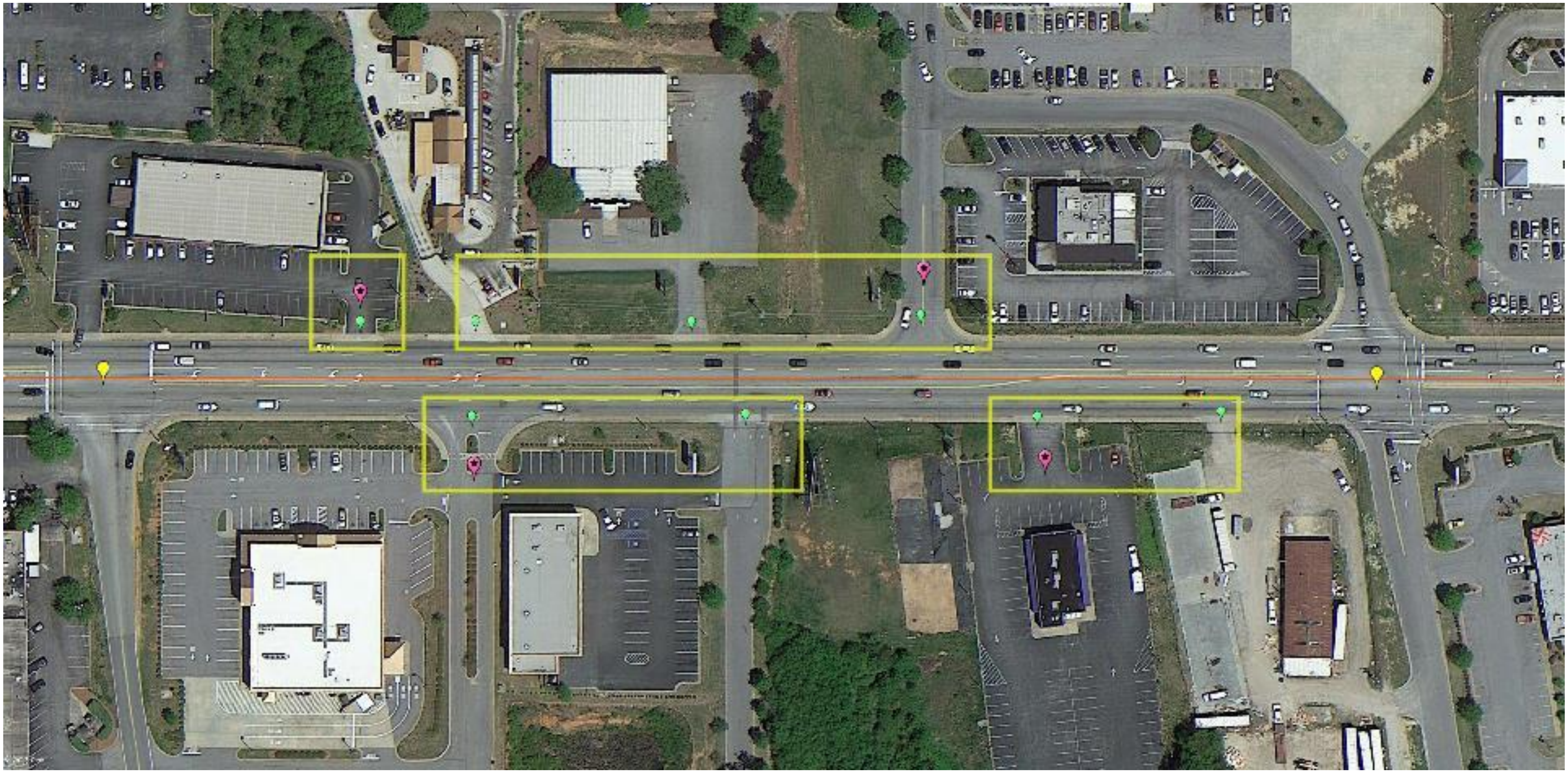


Figure C-15: Consolidation of Driveways along S.C. 146 Greenville, 2nd segment (cont'd with 1st segment)

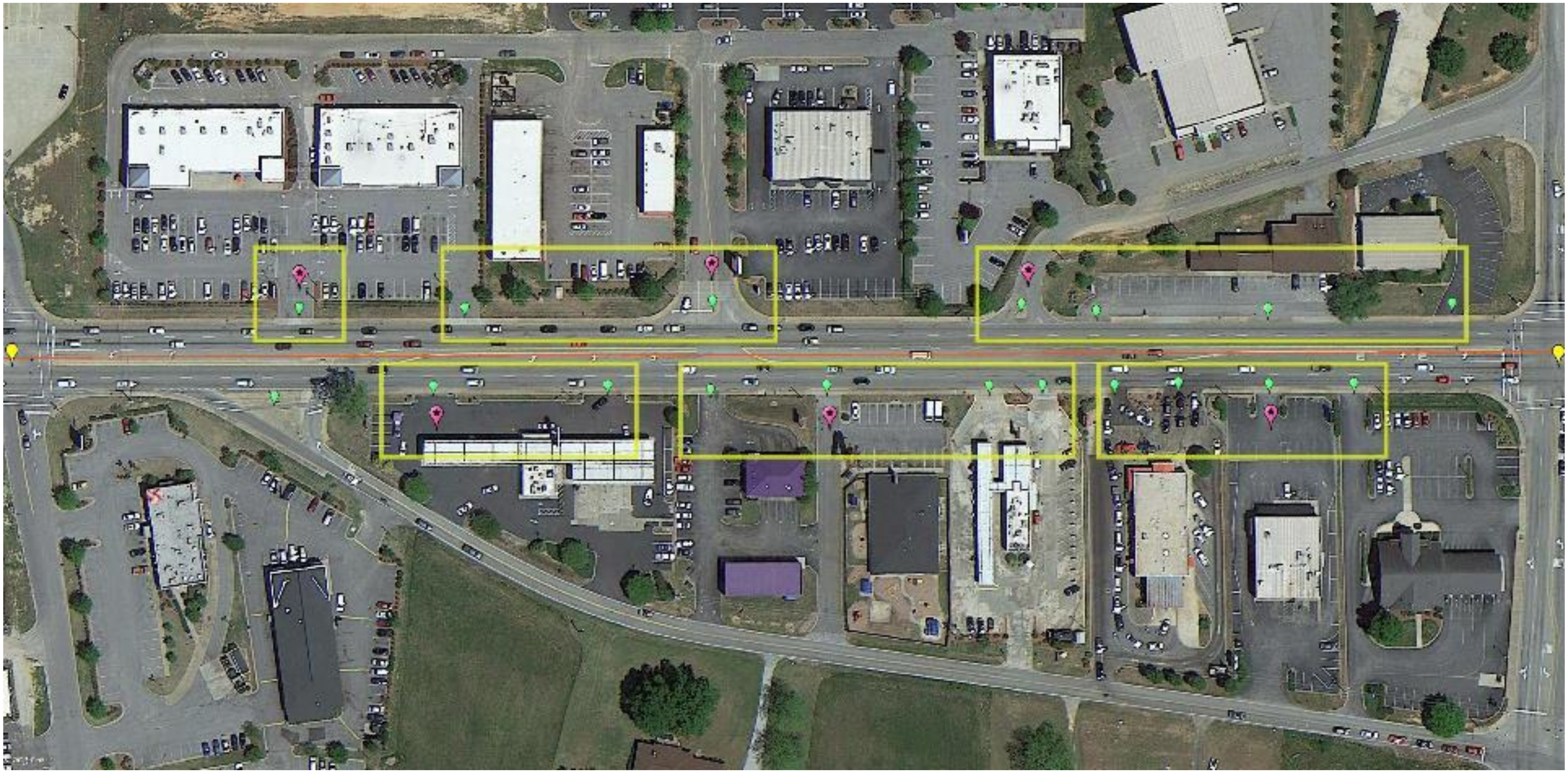


Figure C-15: Consolidation of Driveways along S.C. 146 Greenville, 3rd segment (cont'd with 2nd Segment)

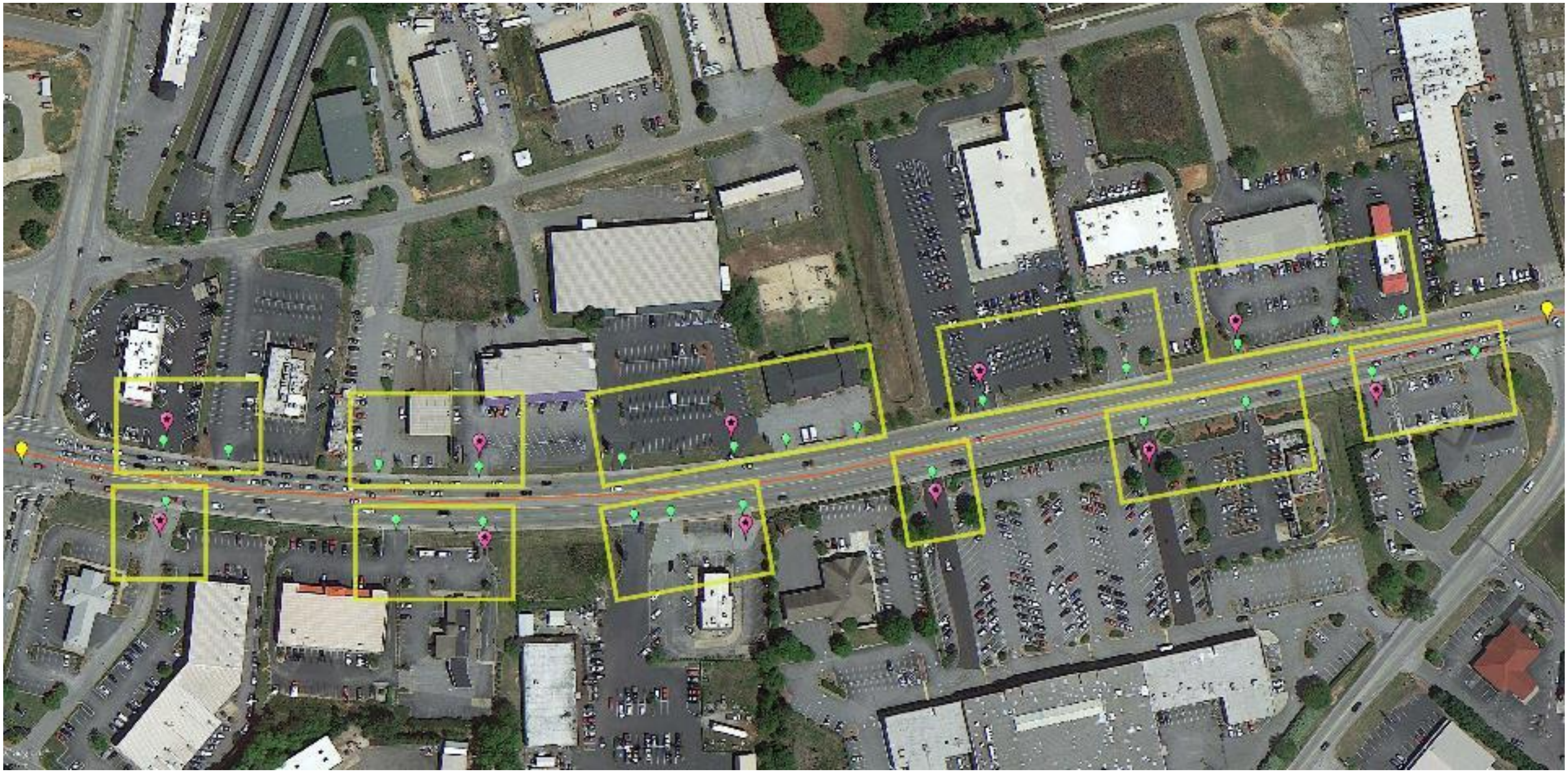


Figure C-15: Consolidation of Driveways along S.C. 146 Greenville, 4th segment (cont'd with 3rd Segment)

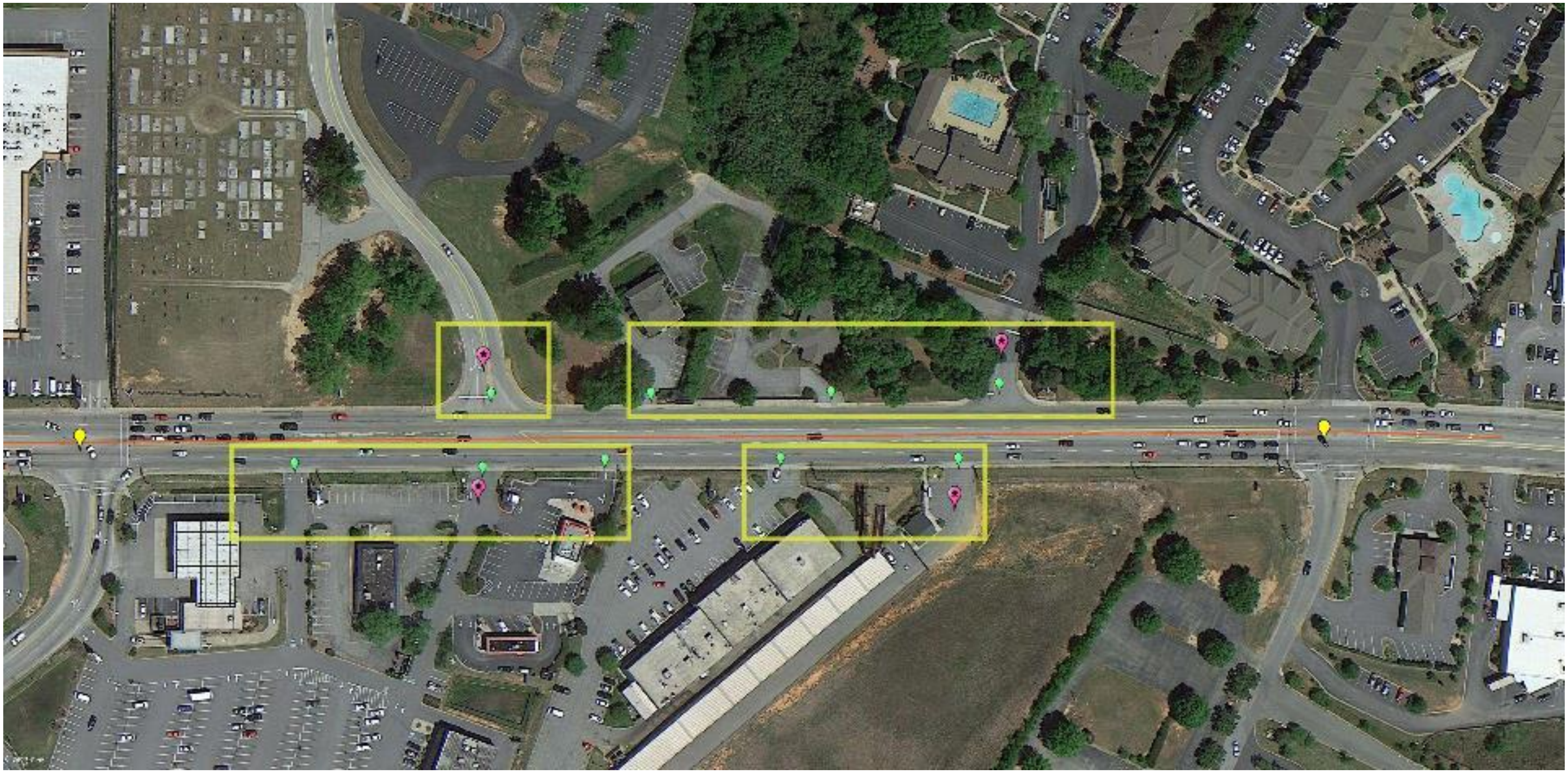


Figure C-15: Consolidation of Driveways along S.C. 146 Greenville, 5th segment (cont'd with 4th segment)

Figure C-16: Resulting Driveways Along Entire S.C. 146 Greenville

Base Model (Before Consolidation)

Consolidated Driveways to Achieve 325' Driveway Spacing SCDOT AMRS Criteria (After Consolidation)

Figure C-17: S.C. 146 Greenville VISSIM Models Before and After Driveway Consolidation

Figure C-18: Consolidation of Driveways along U.S. 29 Greenville #1 Corridor

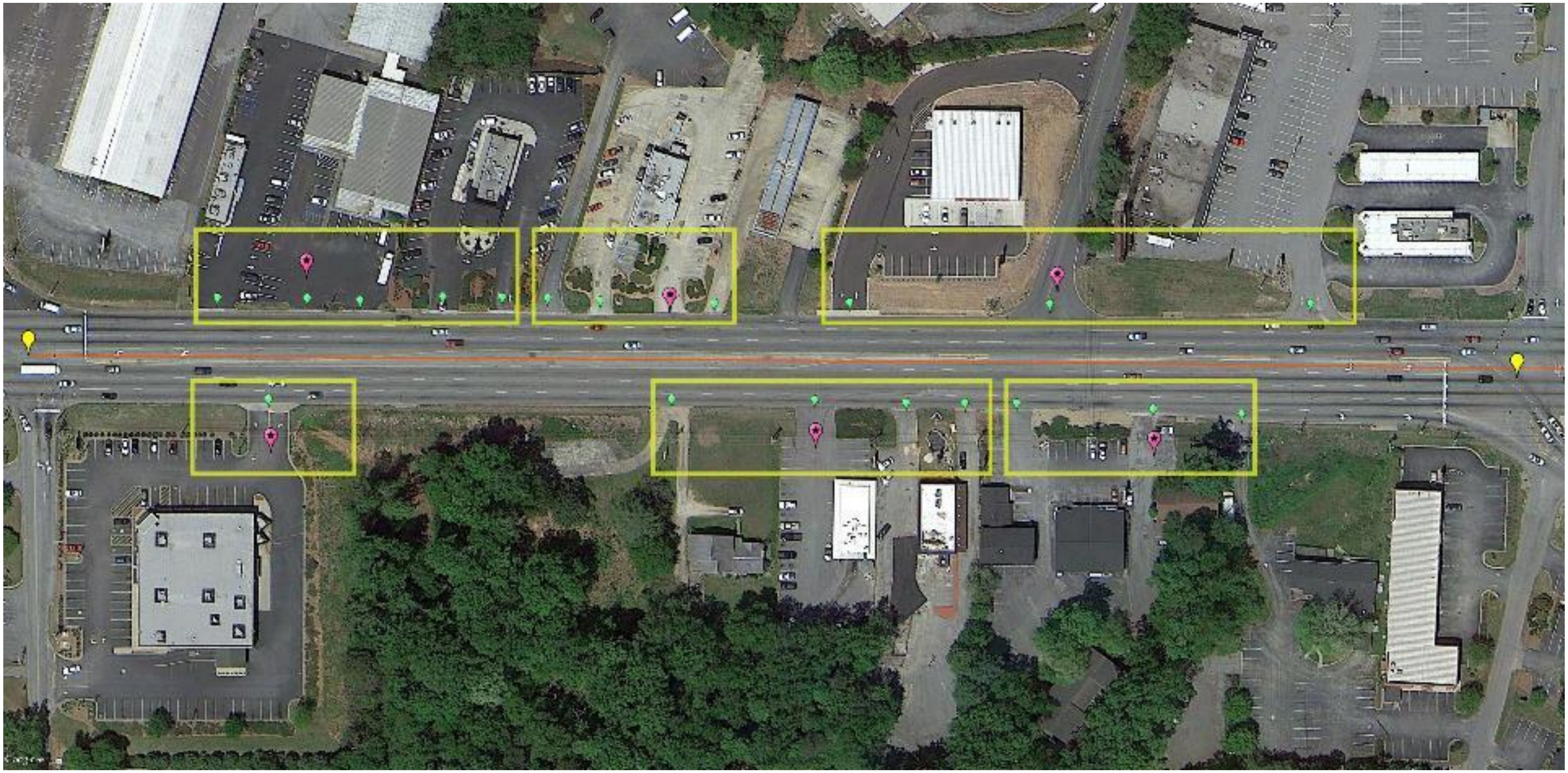


Figure C-19: Consolidation of Driveways along U.S. 29 Greenville #1 Corridor, 1st segment

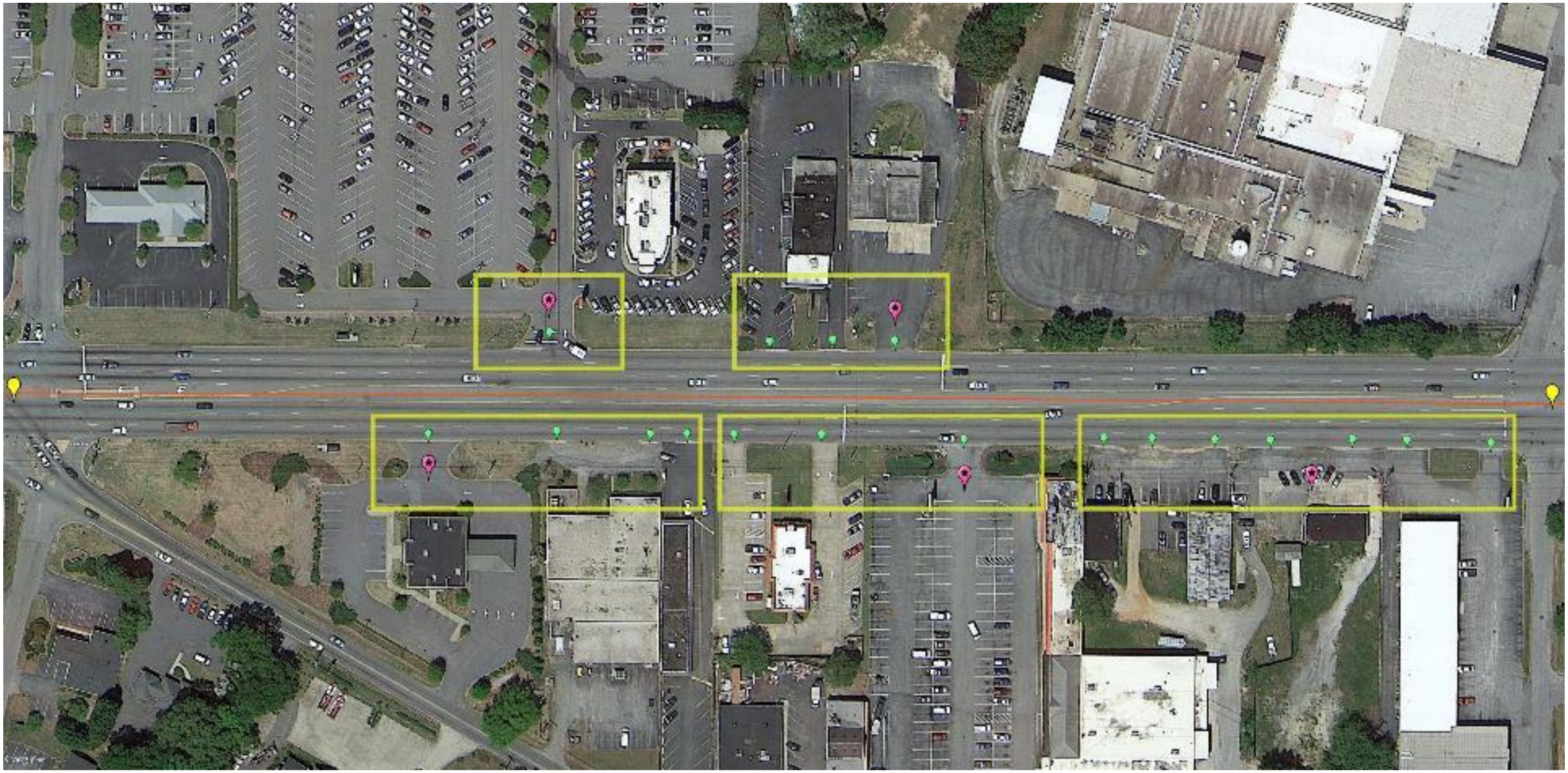


Figure C-19: Consolidation of Driveways along U.S. 29 Greenville #1 Corridor, 2nd segment (cont'd with 1st segment)

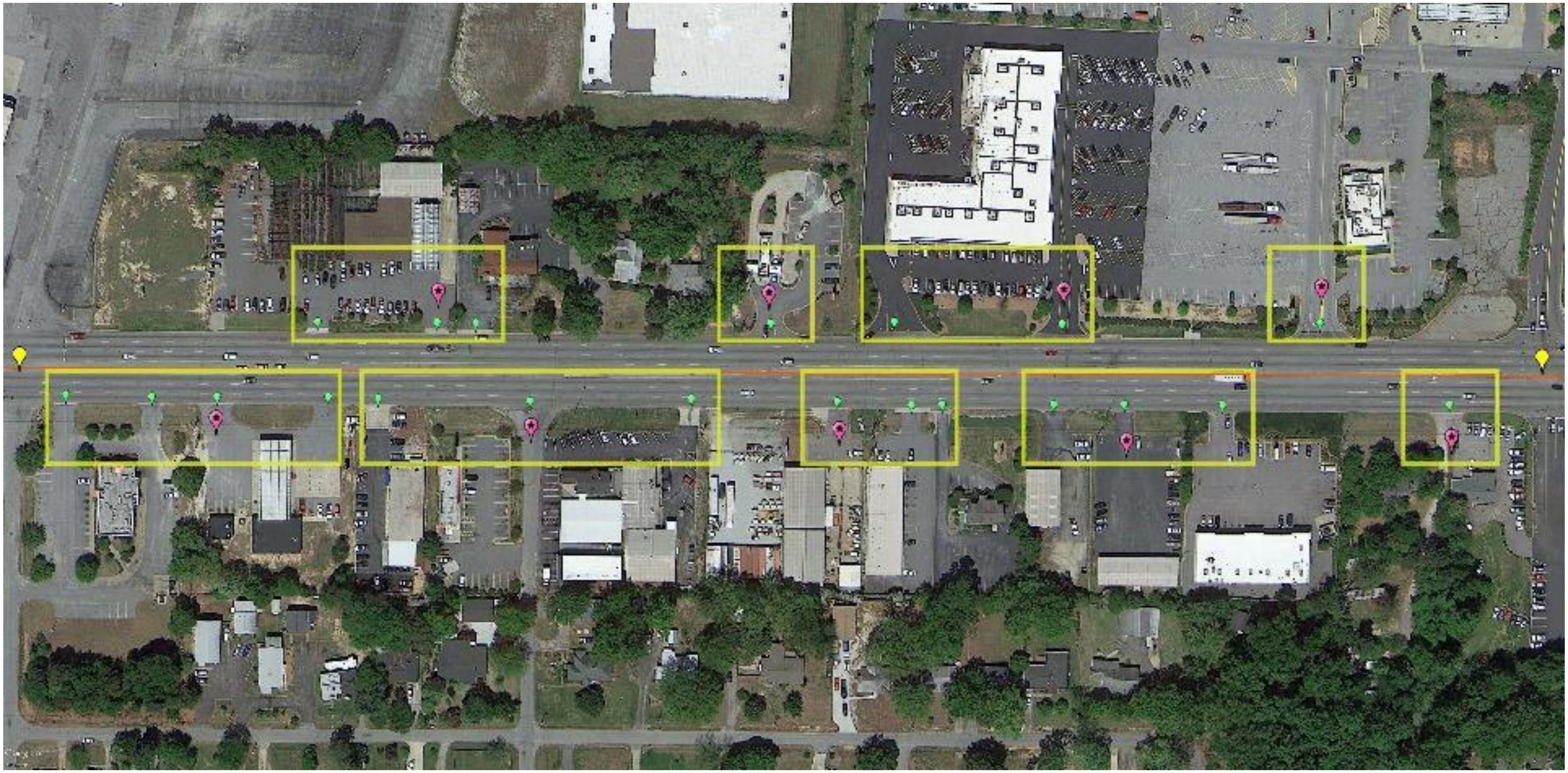


Figure C-19: Consolidation of Driveways along U.S. 29 Greenville #1 Corridor, 3rd segment (cont'd with 2nd segment)

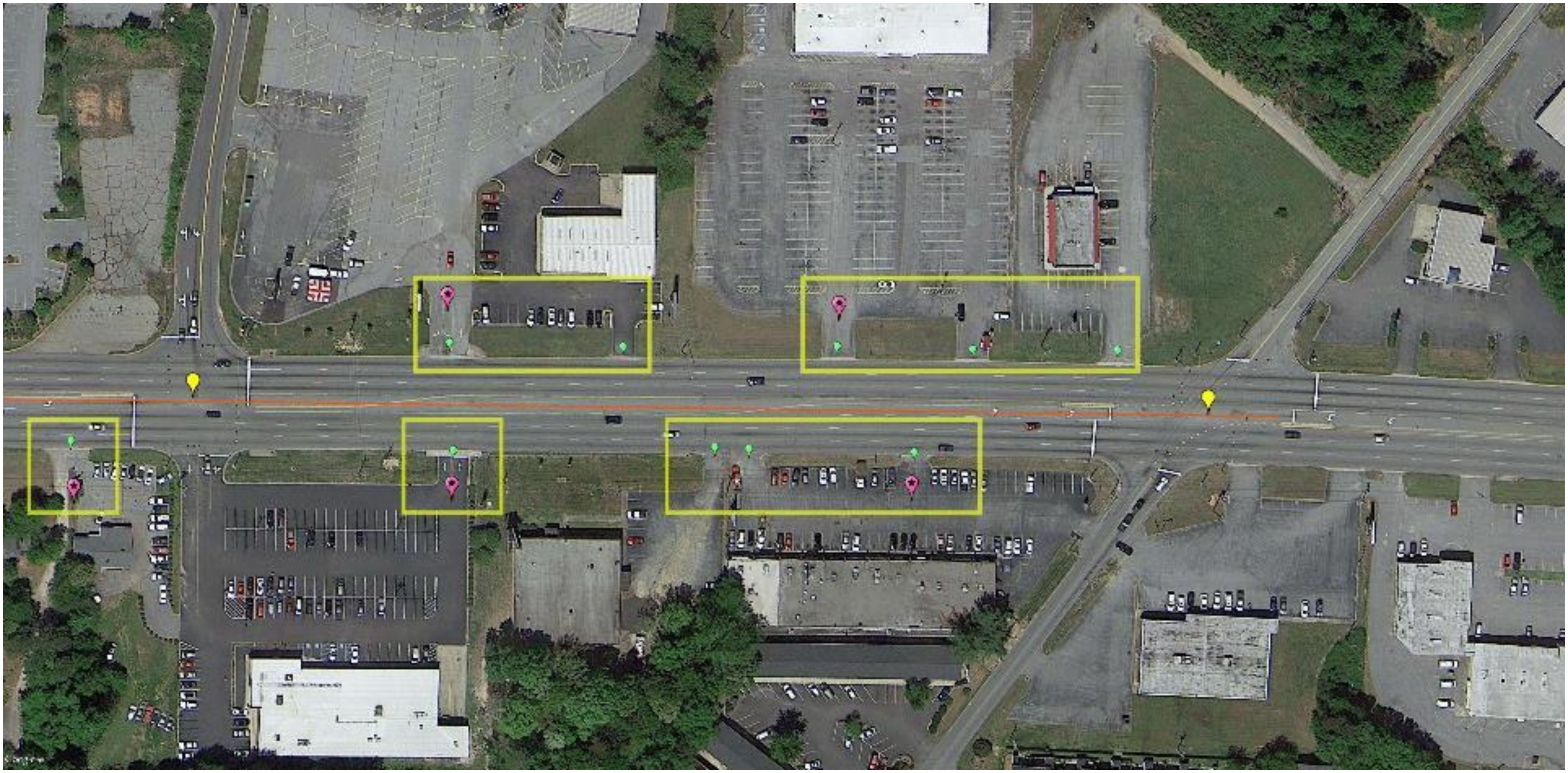
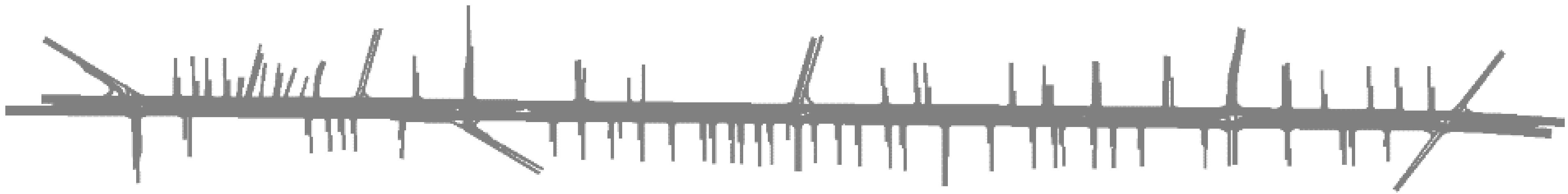
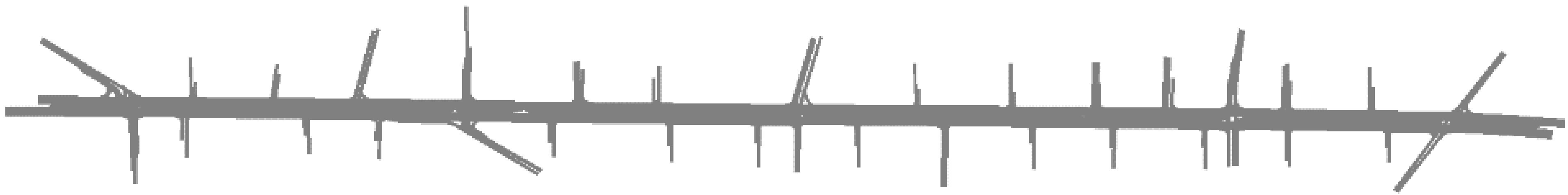


Figure C-19: Consolidation of Driveways along U.S. 29 Greenville #1 Corridor, 4th segment (cont'd with 3rd segment)

Figure C-20: Resulting Driveways Along Entire U.S. 29 Greenville #1 Corridor



Base Model (Before Consolidation)



Consolidated Driveways to Achieve 325’ Driveway Spacing SCDOT AMRS Criteria (After Consolidation)

Figure C-21: U.S. 29 Greenville #1 Corridor VISSIM Models Before and After Driveway Consolidation

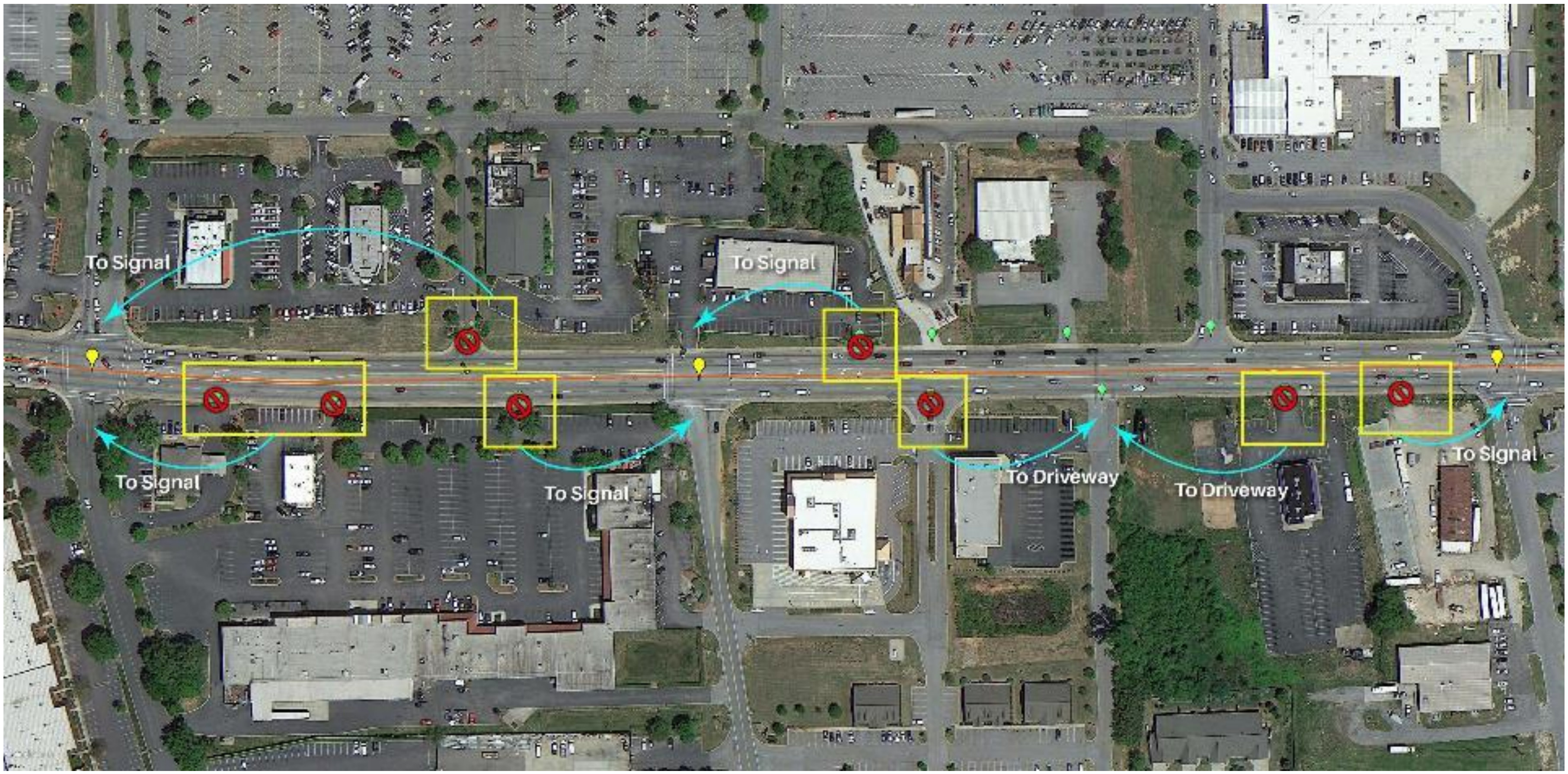


Figure C-22: Closing of Driveways within Minimum Acceptable Corner Clearance along S.C. 146 Greenville (1st and 2nd segments)

Figure C-22: Closing of Driveways within Minimum Acceptable Corner Clearance along S.C. 146 Greenville, 3rd segment

(cont'd with 2nd segment)

Figure C-22: Closing of Driveways within Minimum Acceptable Corner Clearance along S.C. 146 Greenville, 4th segment (cont'd with 3rd segment)

Figure C-22: Closing of Driveways within Minimum Acceptable Corner Clearance along S.C. 146 Greenville, 5th segment (cont'd with 4th segment)

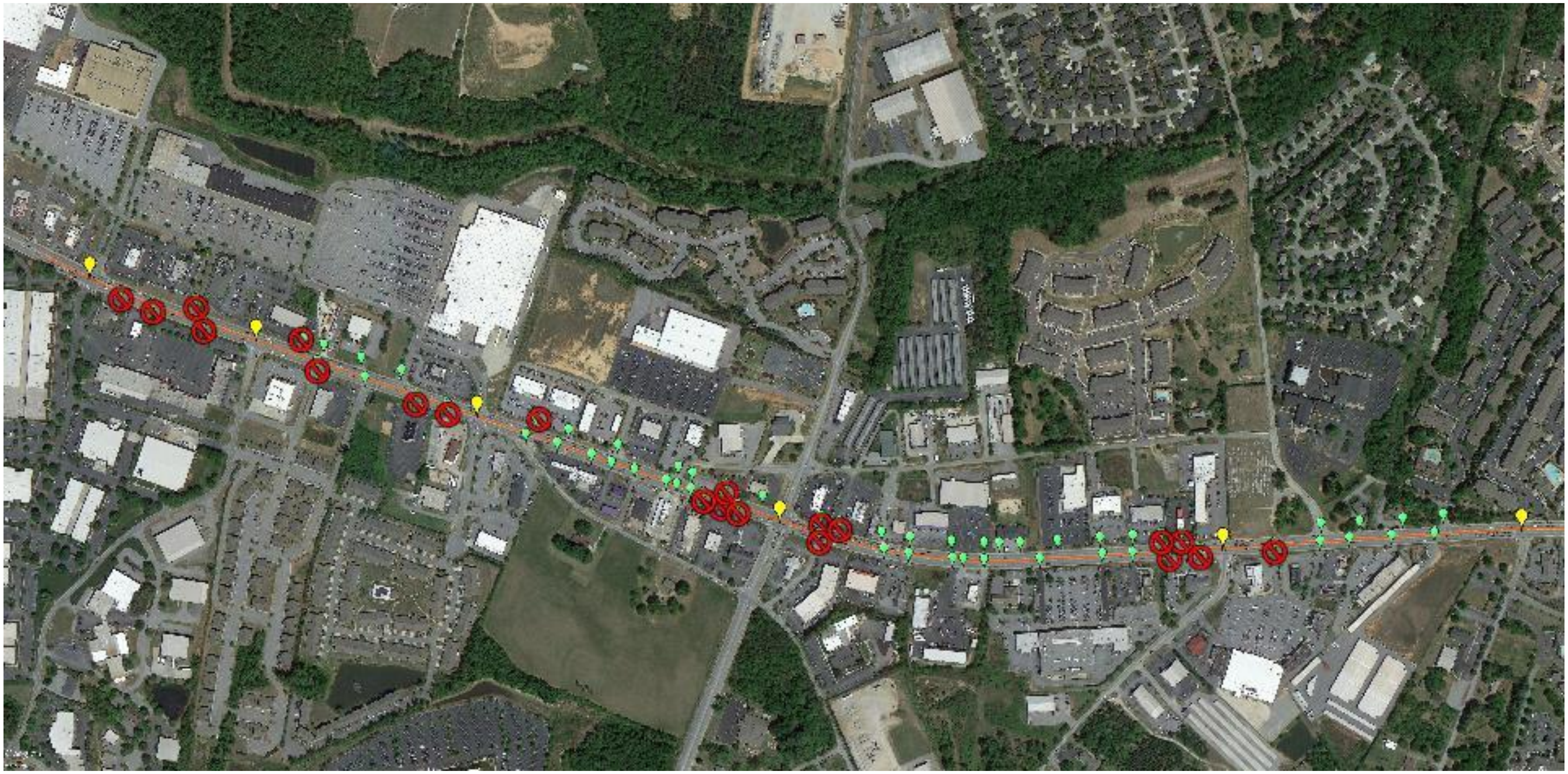
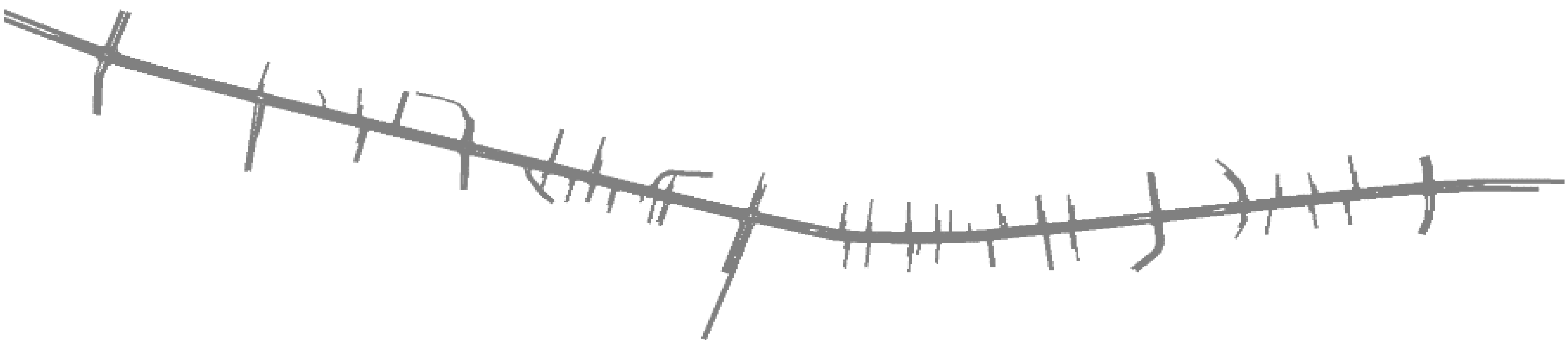


Figure C-23: Closing of Driveways within Minimum Acceptable Corner Clearance along Entire S.C. 146 Greenville

Base Model (Before Closures for Corner Clearance)



Consolidated Driveways to Achieve 325' Corner Clearance SCDOT AMRS Criteria (After Closures)

Figure C-24: S.C. 146 Greenville VISSIM Models Before and After Corner Clearance Driveway Closures

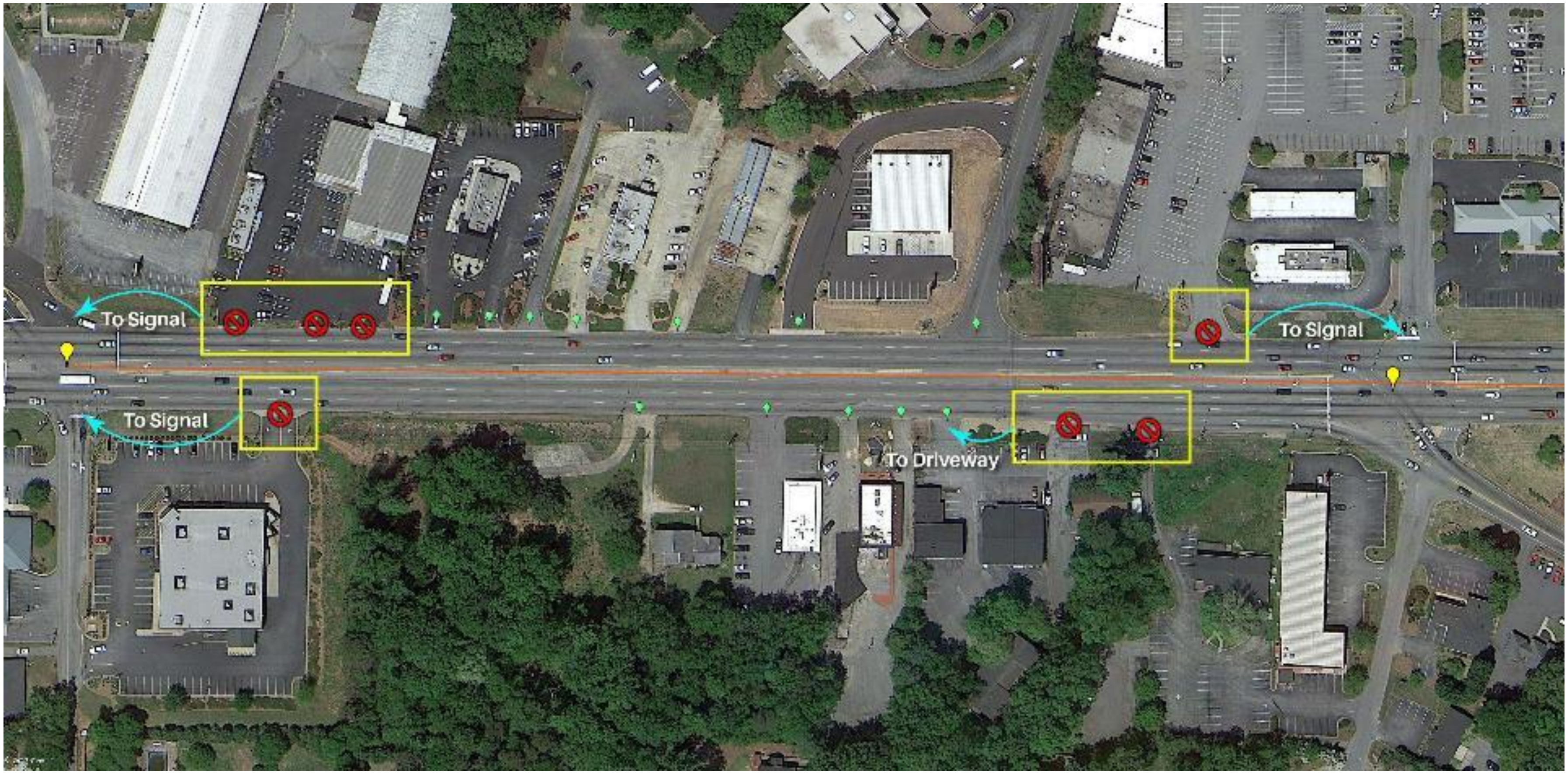


Figure C-25: Closing of Driveways within Minimum Acceptable Corner Clearance along U.S. 29 Greenville #1 (1st segment)

Figure C-25: Closing of Driveways within Minimum Acceptable Corner Clearance along U.S. 29 Greenville #1, 2nd segment (cont'd with 1st segment)

Figure C-25: Closing of Driveways within Minimum Acceptable Corner Clearance along U.S. 29 Greenville #1, 3rd segment (cont'd with 2nd segment)

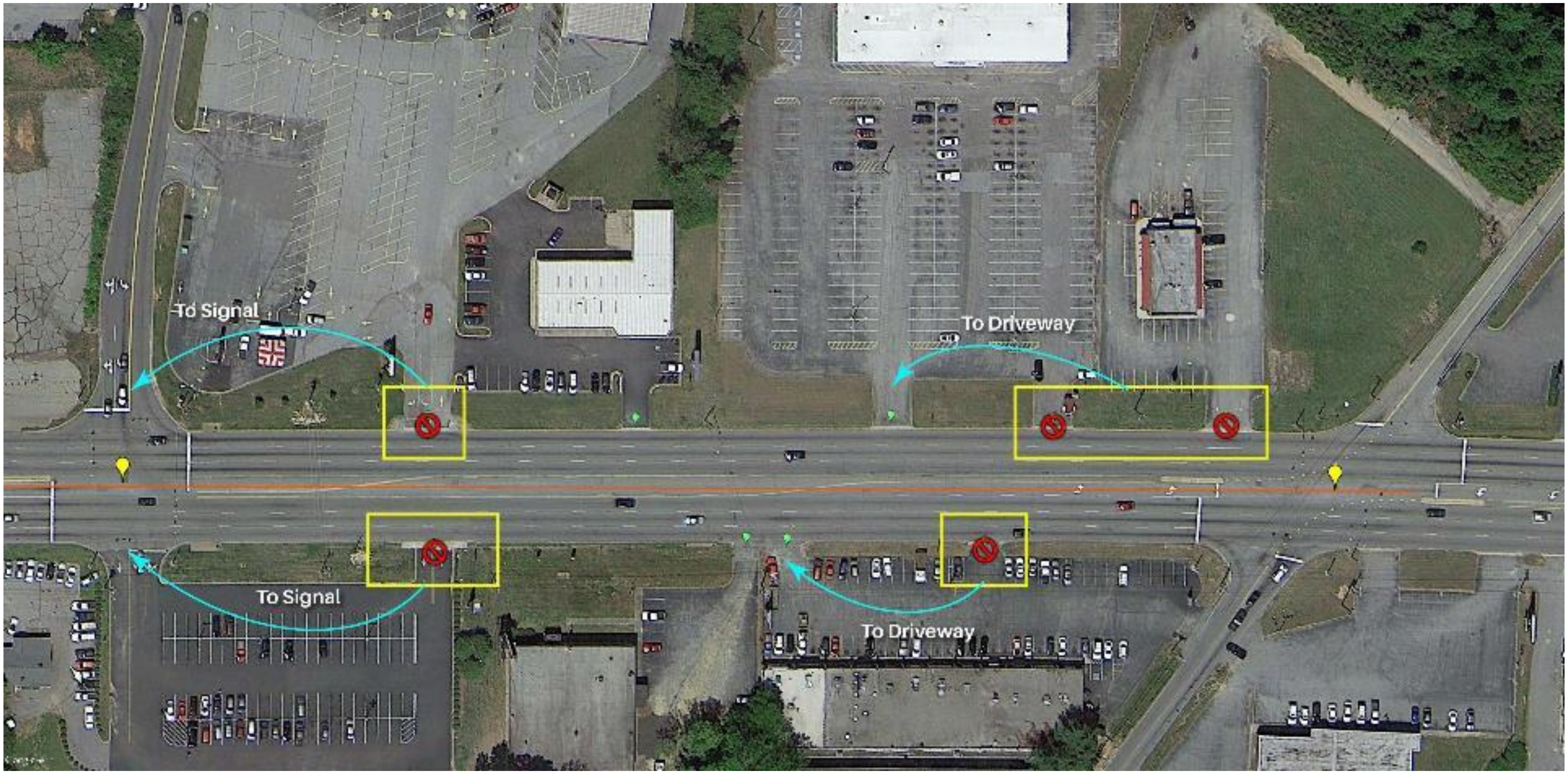


Figure C-25: Closing of Driveways within Minimum Acceptable Corner Clearance along U.S. 29 Greenville #1, 4th segment (cont'd with 3rd segment)

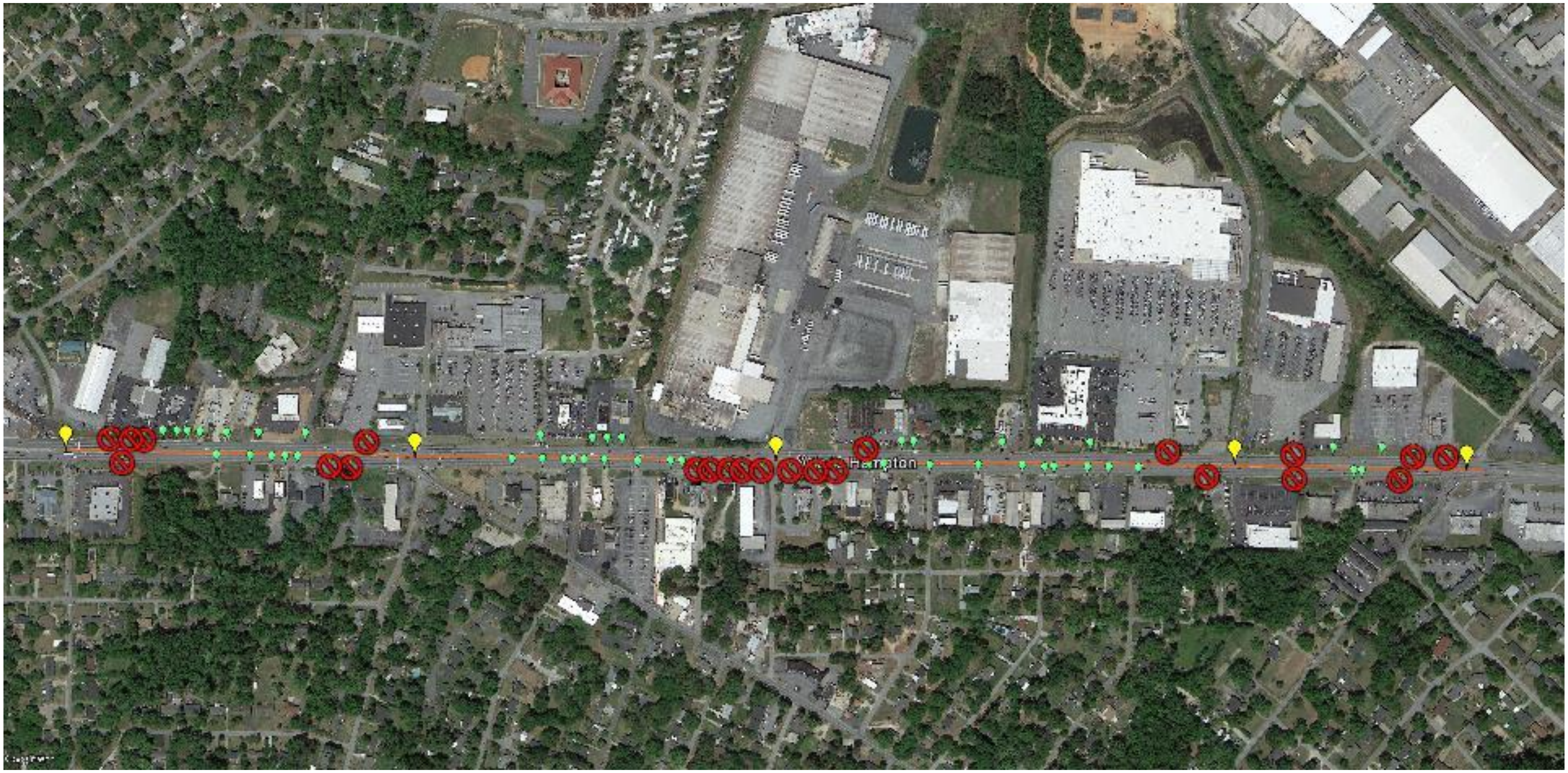
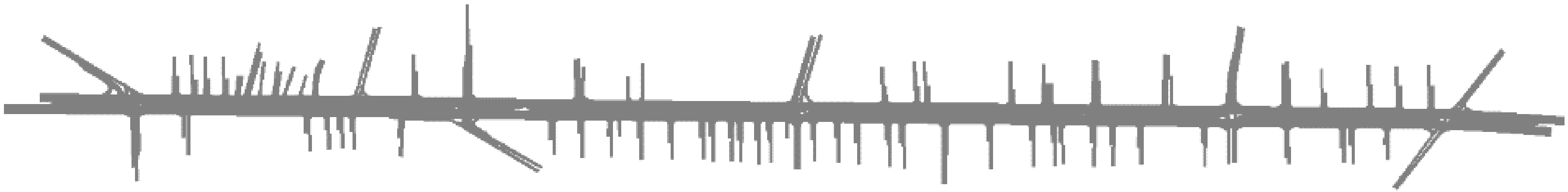
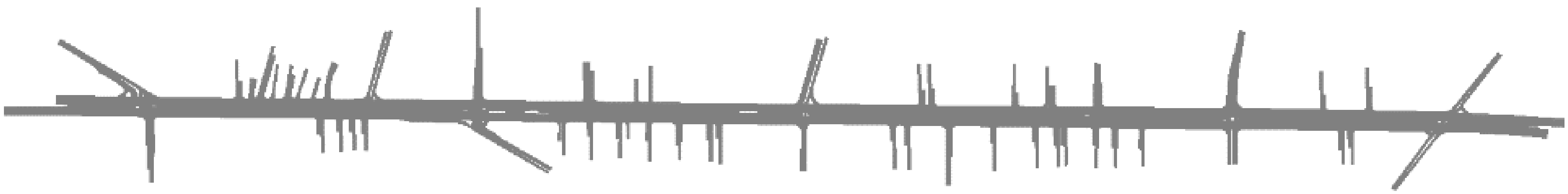


Figure C-26: Closing of Driveways within Minimum Acceptable Corner Clearance along Entire U.S. 29 Greenville #1

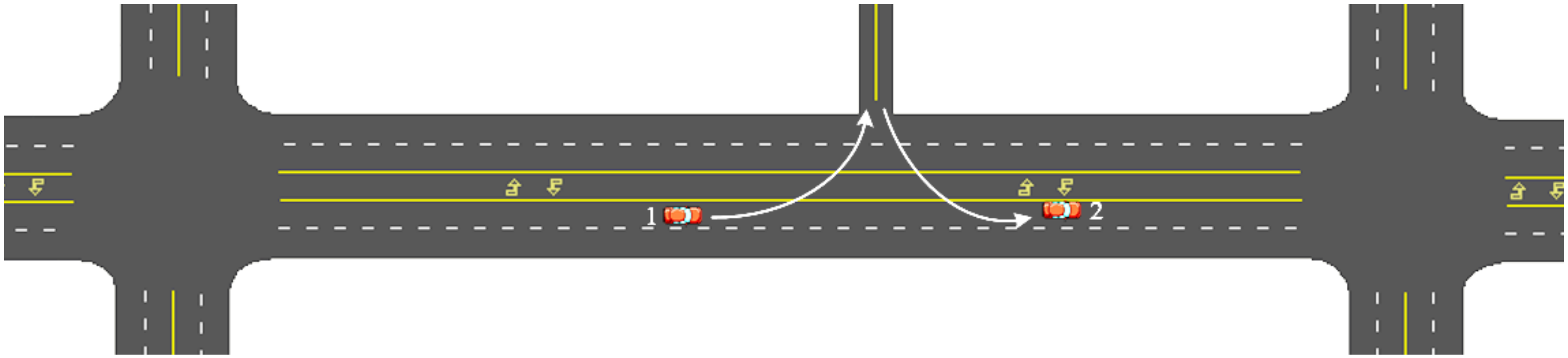


Base Model (Before Closures for Corner Clearance)

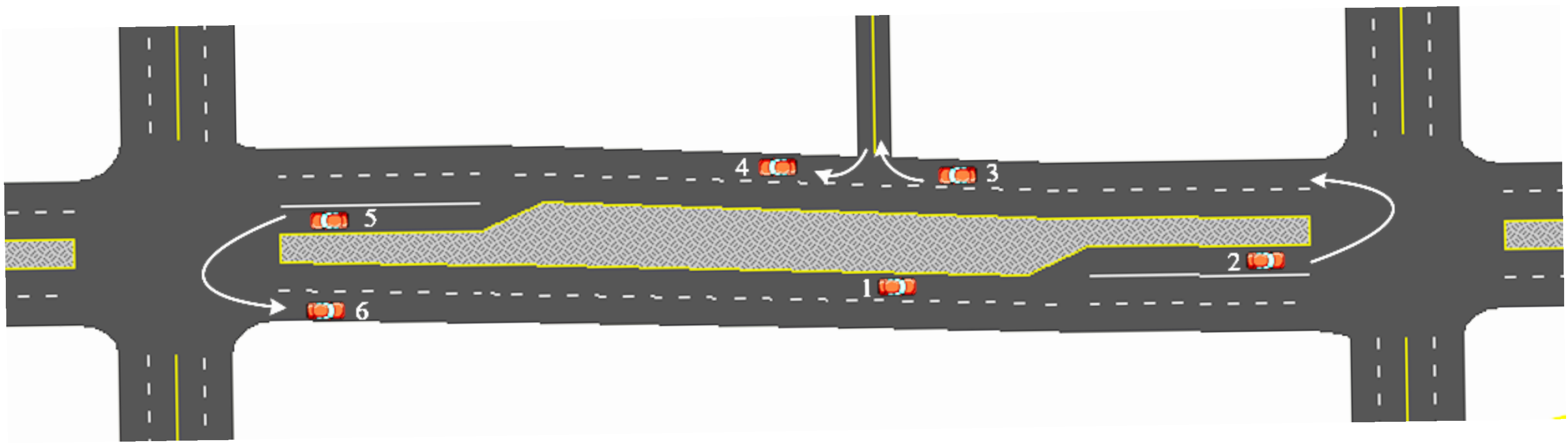


Consolidated Driveways to Achieve 325' Corner Clearance SCDOT AMRS Criteria (After Closures)

Figure C-27: U.S. 29 Greenville #1 VISSIM Models Before and After Corner Clearance Driveway Closures



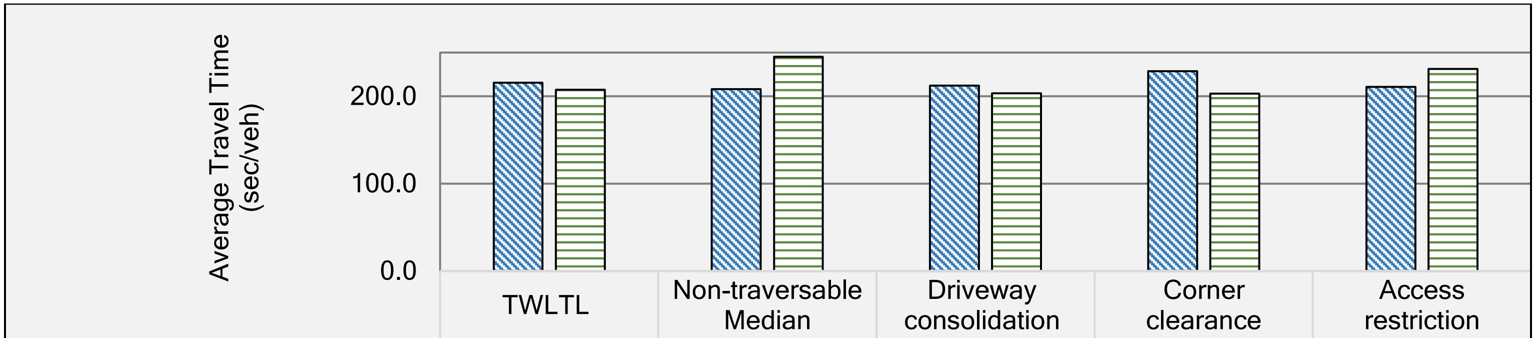
(a)



(b)

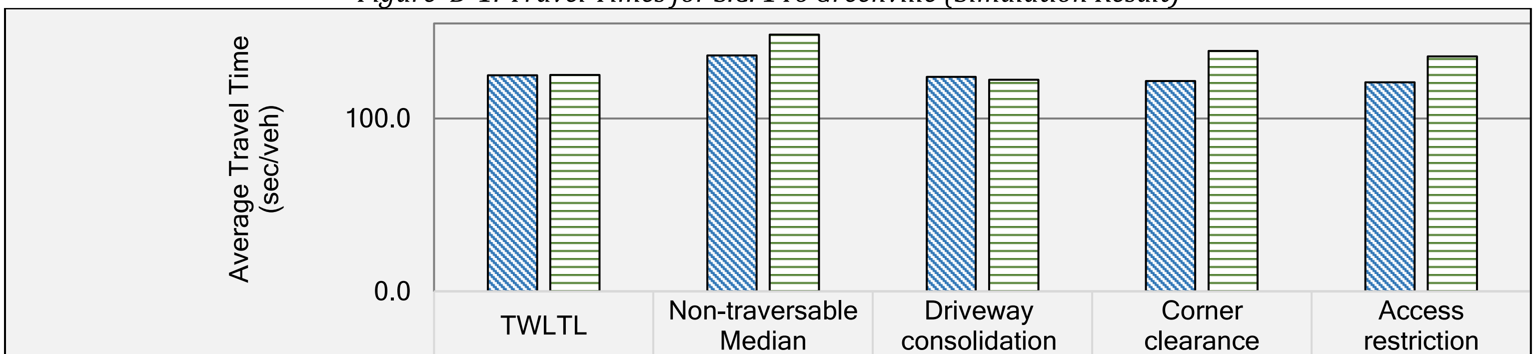
Figure C-28: Sequence of Drivers Maneuver To/From Driveway Before and After Raised Medians Installation: (A) TWLTL Median; (B) Raised Median

APPENDIX D OPERATIONAL ANALYSIS OF ACCESS MANAGEMENT



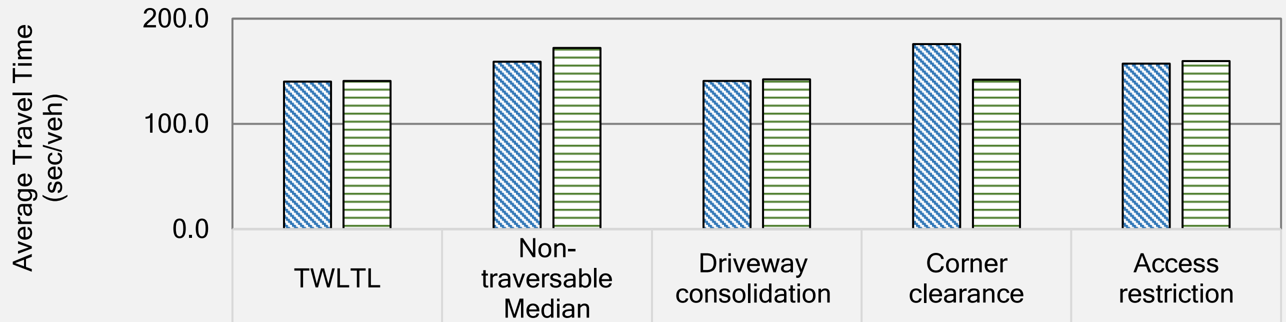
	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	215.6	208.1	212.2	228.6	210.7
WB Avg. Travel Time (sec/veh)	207.5	245.3	203.5	203.1	231.2

Figure D-1: Travel Times for S.C. 146 Greenville (Simulation Result)



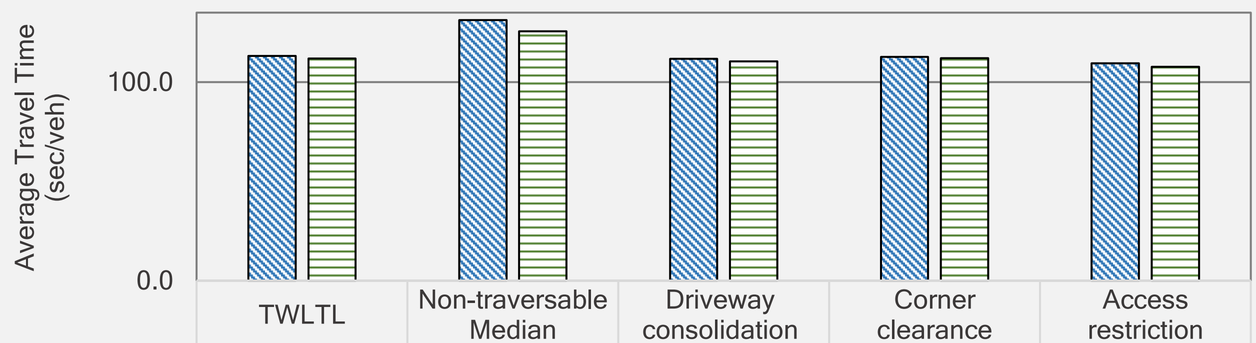
	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
SB Avg. Travel Time (sec/veh)	125.0	136.5	124.1	121.7	121.0
NB Avg. Travel Time (sec/veh)	125.1	148.4	122.5	139.1	136.0

Figure D-2: Travel Times for U.S. 176 Richland (Simulation Result)



	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	140.2	159.1	141.0	175.7	157.2
WB Avg. Travel Time (sec/veh)	140.7	172.1	142.5	142.1	159.8

Figure D-3: Travel Times for U.S. 1 Richland #1 (Simulation Result)



	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	113.1	131.2	111.7	112.6	109.5
WB Avg. Travel Time (sec/veh)	111.9	125.7	110.4	112.1	107.7

Figure D-4: Travel Times for U.S. 29 Greenville #1 (Simulation Result)

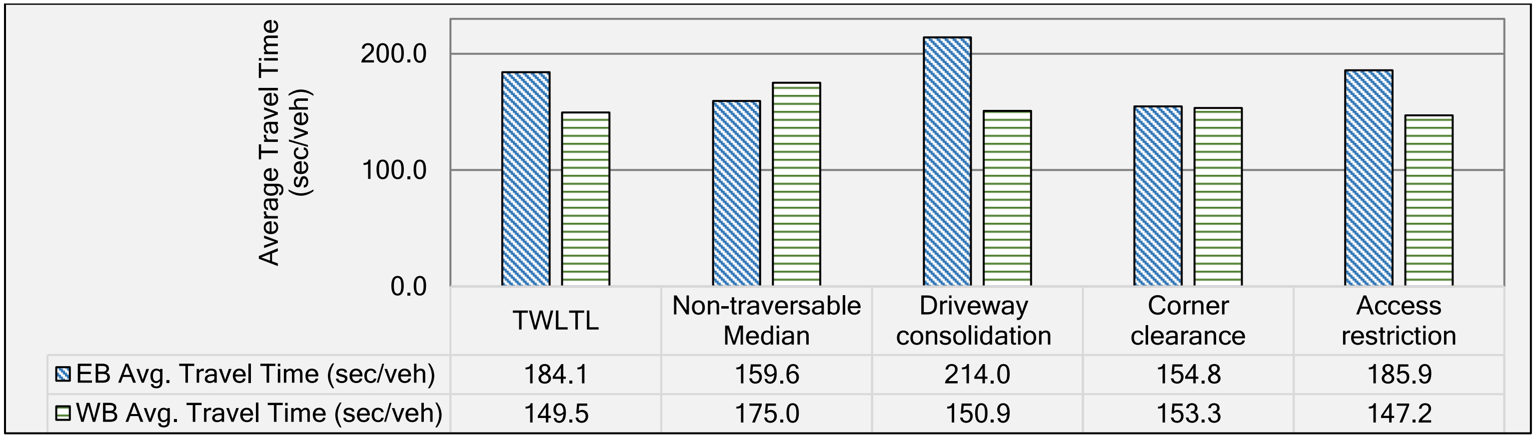


Figure D-5: Travel Times for U.S. 29 Greenville #2 (Simulation Result)

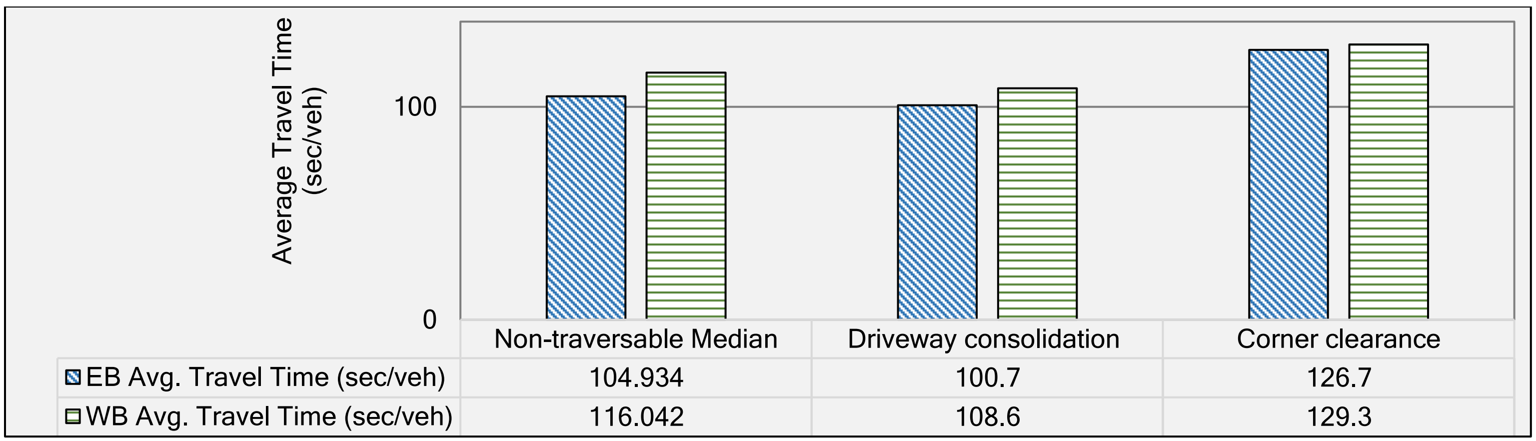
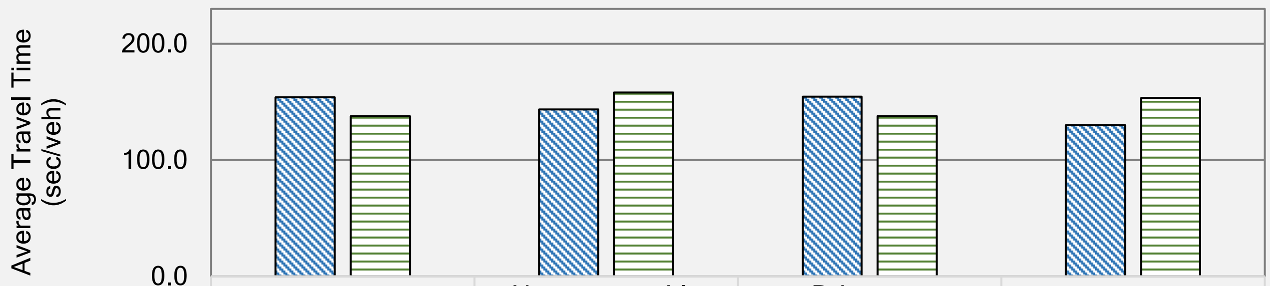
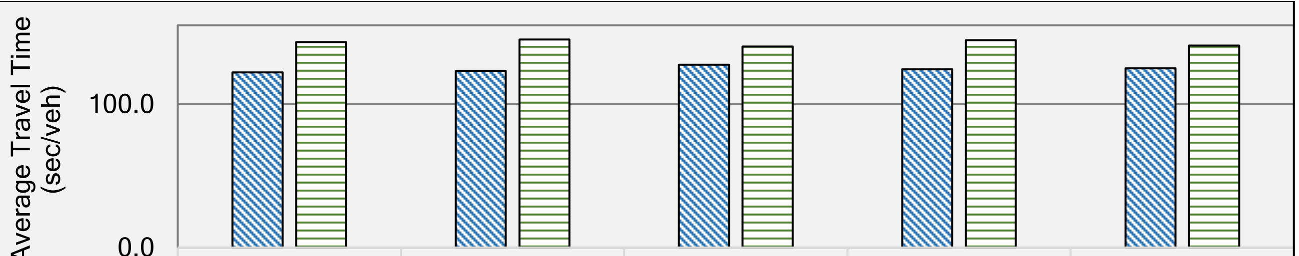


Figure D-6: Travel Times for U.S. 17 Charleston (Simulation Result)



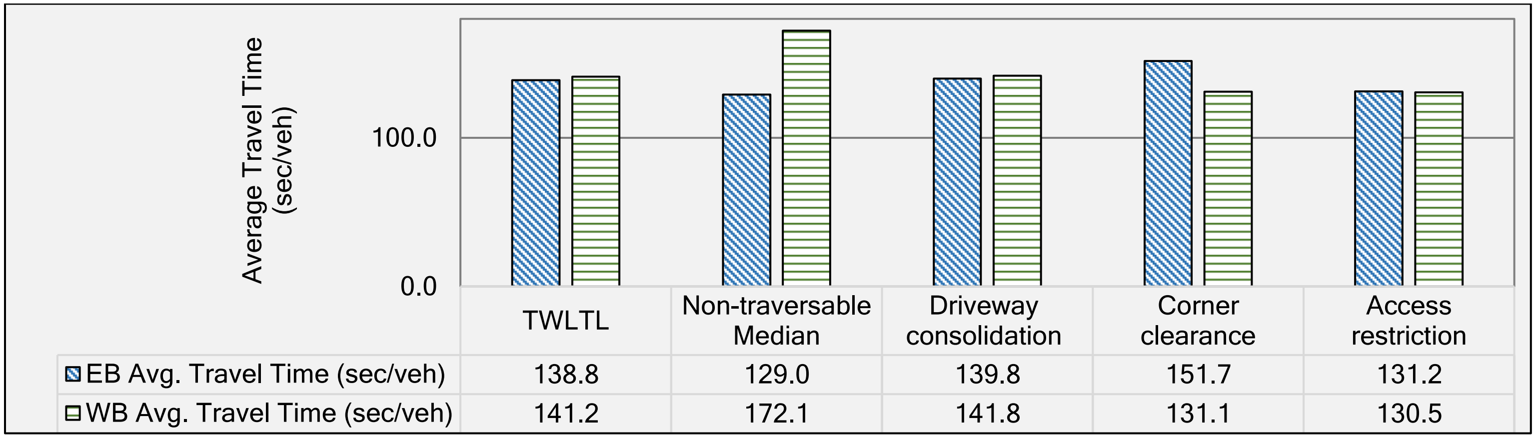
	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance
EB Avg. Travel Time (sec/veh)	154.0	143.4	154.4	130.2
WB Avg. Travel Time (sec/veh)	137.7	158.0	137.9	153.3

Figure D-7: Travel Times for U.S. 1 Richland #2 (Simulation Result)



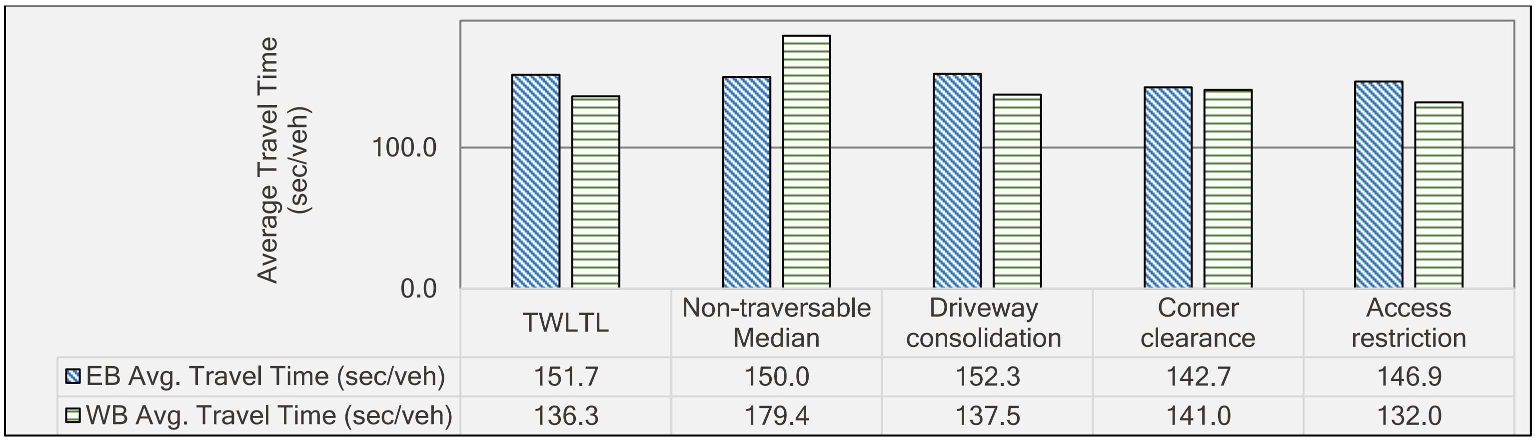
	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	122.1	123.2	127.6	124.3	125.0
WB Avg. Travel Time (sec/veh)	143.3	145.1	140.2	144.5	140.7

Figure D-8: Travel Times for U.S. 378 Lexington #1 (Simulation Result)



	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	138.8	129.0	139.8	151.7	131.2
WB Avg. Travel Time (sec/veh)	141.2	172.1	141.8	131.1	130.5

Figure D-9: Travel Times for U.S. 378 Lexington #2 (Simulation Result)



	TWLTL	Non-traversable Median	Driveway consolidation	Corner clearance	Access restriction
EB Avg. Travel Time (sec/veh)	151.7	150.0	152.3	142.7	146.9
WB Avg. Travel Time (sec/veh)	136.3	179.4	137.5	141.0	132.0

Figure D-10: Travel Times for U.S. 76 Florence (Simulation Result)

Table D-1: Statistical Testing Summary for Mainline Travel Time (Simulation Result)

Corridors	***Statistically significant difference***			
	Non-traversable Median	***Driveway consolidation***	***Corner clearance from Intersection***	***Access restriction***
S.C. 146 Greenville	Yes	No	Yes	Yes
U.S. 176 Richland	Yes	Yes	Yes	Yes
U.S. 1 Richland #1	Yes	Yes	Yes	Yes
U.S.29 Greenville #1	Yes	Yes	No	Yes
U.S. 29 Greenville #2	No	No	No	No
U.S. 17 Charleston	-	Yes	Yes	-
U.S. 1 Richland #2	Yes	No	Yes	-
U.S. 378 Lexington #1	No	No	Yes	No
U.S. 378 Lexington #2	Yes	No	No	Yes
U.S. 76 Florence	No	No	No	No

Table D-2: Mainline Operational Conditions for Different Scenarios (Simulation Result)

Corridors	Existing Condition			Percent changes compared to existing condition											
				Non-traversable Median			Driveway consolidation			Corner clearance from intersection			Access restriction		
	Delay (sec/veh)	Stopped Delay (sec/veh)	Number of Stops (sec/veh	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)
S.C. 146 Greenville*	63.8	17.7	1.9	32	37	30	0	-1	0	-2	-17	1	12	-4	7
U.S. 176 Richland*	33.0	12.3	0.9	53	70	47	-6	-3	-2	16	-25	12	12	-33	7
U.S. 1 Richland #1*	20.0	8.3	0.7	58	96	28	17	13	15	31	34	42	23	31	26
U.S.29 Greenville #1*	23.8	8.2	0.8	68	38	62	-5	-7	-5	1	-12	2	-16	-41	-26
U.S. 29 Greenville #2*	58.9	21.3	1.5	-16	-26	-16	11	8	14	-52	-60	-47	-42	-53	-30
U.S. 17 Charleston**	22.8	6.9	0.7	-	-	-	-25	-48	-32	71	<-100	39	-	-	-
U.S. 1 Richland #2*	57.3	28.1	1.2	8	6	1	0	2	1	-29	-62	-22	-	-	-
U.S. 378 Lexington #1*	25.4	5.5	0.8	0.4	-20	-17.5	0	-1.8	3.8	2.4	13	12.5	-3	1.8	-5
U.S. 378 Lexington #2*	32.6	12.0	1.1	35	79	21	2	3	2	25	41	9	-29	-51	-38
U.S. 76 Florence*	44.0	24.5	1.4	50	37	51	4	6	3	7	5	20	-11	-10	-13

** Existing condition with TWLTL*

*** Existing condition with Raised Median*

Table D-3: Statistical Testing Summary for Mainline Operational Conditions (Simulation Result)

Corridors	*Non-traversable Median*			*Driveway consolidation*			*Corner clearance from Intersection*			*Access restriction*		
	Delay	*Stopped Delay*	*Number of Stops*	*Delay*	*Stopped Delay*	*Number of Stops*	*Delay*	*Stopped Delay*	*Number of Stops*	*Delay*	*Stopped Delay*	*Number of Stops*
S.C. 146 Greenville	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes
U.S. 176 Richland	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
U.S. 1 Richland #1	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
U.S.29 Greenville #1	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Yes
U.S. 29 Greenville #2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
U.S. 17 Charleston	-	-	-	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
U.S. 1 Richland #2	Yes	Yes	No	No	No	No	Yes	Yes	Yes	-	-	-
U.S. 378 Lexington #1	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No	No
U.S. 378 Lexington #2	Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes
U.S. 76 Florence	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes

Table D-4: Average Travel Time for Right-in[44] Driveway Traffic (Simulation Result)

Corridors	TWLTL	Non-traversable median		Driveway consolidation		Corner clearance from intersection		Access restriction	
	sec/veh	sec/veh	%**	sec/veh	%**	sec/veh	%**	sec/veh	%**
S.C. 146 Greenville	24*	23	-2.6	15	-39	19	-23	19	-20
U.S. 176 Richland	18*	19	6	8	-55	12	-32	18	2
U.S. 1 Richland #1	30*	35	16	14	-52	33	8	35	14
U.S.29 Greenville #1	17*	17	3	7	-55	12	-28	16	-1
U.S. 29 Greenville #2	17*	18	11	12	-28	11	-32	18	11
U.S. 17 Charleston	-	24*	-	25	4	22	-8	-	-
U.S. 1 Richland #2	18*	21	14	14	-29	17	-6	-	-
U.S. 378 Lexington #1	21.6*	22	1.9	23	6.5	21.9	1.4	21.9	1.4
U.S. 378 Lexington #2	16*	16	3	11	-33	10	-34	15	-6
U.S. 76 Florence	10*	14	37	5	-45	5	-53	13	28

** Existing access management strategies on corridors*

***Percent change (%) compared to existing Condition*

[44] Right-in movements from the immediate upstream intersection to the driveway

Table D-5: Operational Conditions for Right-in[45] Driveway traffic (Simulation Result)

Corridors	Existing Condition			Percent changes compared to existing condition											
				Non-traversable Median			Driveway consolidation			Corner clearance from intersection			Access restriction		
	Delay (sec/veh)	Stopped Delay (sec/veh)	Number of Stops (sec/veh	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)
S.C. 146 Greenville*	2.12	0.11	0.03	-12	-42.5	-32.8	51.6	>100	56.4	>100	>100	>100	25.5	57.1	10.2
U.S. 176 Richland*	1.69	0.01	0.01	29.2	>100	30.1	25.7	>100	69.9	24.9	>100	80.6	14.8	91.7	31.1
U.S. 1 Richland #1*	0.88	0.01	0.01	55.9	>100	>100	4.9	-60	-73.1	>100	>100	>100	20.9	>100	19.2
U.S.29 Greenville #1*	0.63	0.03	0.01	81.2	>100	>100	34.8	25	12.5	77.6	>100	32.3	77.6	>100	32.3
U.S. 29 Greenville #2*	2.60	0.56	0.04	-39.4	-71.7	-7.9	33.7	>100	66.3	-70.5	-87.5	-64.2	-55.9	-75.3	-53.7
U.S. 17 Charleston**	1.3	0.05	0.03	-	-	-	4.4	<-100	34.5	59	>100	72.5	-	-	-
U.S. 1 Richland #2*	3.04	0.14	0.01	16.2	>100	>100	-23.9	-90.7	-69	-47.4	-90.7	-43.1	-	-	-
U.S. 378 Lexington #1*	1.02	0.002	0.002	19.6	50	-15	10.8	50	-40	-1	-55	0	-4	50	-50
U.S. 378 Lexington #2*	1.40	0.01	0.01	37.8	>100	91.6	10.3	>100	38	32.5	>100	>100	-1	-20	1.1
U.S. 76 Florence*	0.42	0.00	0.00	20.8	>100	>100	10.7	0.00	80	>100	>100	>100	10.7	0	>100

** Existing condition with TWLTL*

*** Existing condition with Raised Median*

[45] Right-in movements from the immediate upstream intersection to the driveway

Table D-6: Average Travel Time for Left-in[46] Driveway Traffic (Simulation Result)

Corridors	TWLTL	Non-traversable Median		Driveway consolidation		Corner clearance from intersection		Access restriction	
	sec/veh	**sec/veh**	**%****	**sec/veh**	**%****	**sec/veh**	**%****	**sec/veh**	**%****
S.C. 146 Greenville	22*	26	18	13	-41	20	-9	29	30
U.S. 176 Richland	30*	64	>100	14	-54	26	-15	33	8
U.S. 1 Richland #1	23*	81	>100	13	-44	29	23	32	35
U.S.29 Greenville #1	30*	58	96	16	-47	24	-21	35	16
U.S. 29 Greenville #2	29*	55	88	27	-7	18	-38	39	34
U.S. 17 Charleston	-	23*	-	22	-4	25	9	-	-
U.S. 1 Richland #2	23*	67	66	20	-15	26	12	-	-
U.S. 378 Lexington #1	26.7*	77.3	>100	27.9	4.5	28.1	5.2	29.2	9.4
U.S. 378 Lexington #2	11*	36	>100	8	-33	8	-26	18	57
U.S. 76 Florence	10*	22	>100	5	-50	4	-56	17	73

** Existing access management strategies on corridors*

***Percent change (%) compared to existing Condition*

[46] Left-in movements from the immediate upstream intersection to the driveway

Table D-7: Operational Conditions for Left-in[47] Driveway Traffic (Simulation Result)

Corridors	Existing Condition			Percent changes compared to existing condition											
				Non-traversable Median			Driveway consolidation			Corner clearance from intersection			Access restriction		
	Delay (sec/veh)	Stopped Delay (sec/veh)	Number of Stops (sec/veh	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)
S.C. 146 Greenville*	13.94	7.98	0.75	1.26	1.94	-3.35	>100	>100	70.84	30.26	5.15	-4.46	>100	>100	51.17
U.S. 176 Richland*	21.32	6.41	0.69	7.94	85.66	90.11	-3.49	-0.11	1.37	6.18	8.50	3.36	-1.29	16.04	19.70
U.S. 1 Richland #1*	4.25	1.32	0.22	89.07	70.81	71.81	22.26	24.32	28.25	>100	>100	95.15	29.59	54.70	33.61
U.S.29 Greenville #1*	11.55	6.69	0.71	46.40	-6.80	13.55	-3.25	-4.93	4.49	-14.94	-20.09	-12.53	-14.94	-20.09	-12.53
U.S. 29 Greenville #2*	59.72	50.02	0.83	-69.37	>100	-7.64	-51.59	-59.00	-20.63	-82.98	-92.28	-34.82	-57.87	-71.17	21.54
U.S. 17 Charleston**	3	0.12	0.03	-	-	-	-15	>100	34.2	76.7	>100	>100	-	-	-
U.S. 1 Richland #2*	5.37	1.57	0.21	>100	>100	>100	12.42	8.05	8.56	39.69	>100	47.70	-	-	-
U.S. 378 Lexington #1*	7.1	2.5	0.36	>100	>100	>100	-4.1	-5.2	-11	-1.55	-8.8	-2.8	-0.6	-3.2	-5.6
U.S. 378 Lexington #2*	6.64	2.73	0.34	>100	>100	>100	4.64	-2.10	2.02	76.33	>100	13.23	>100	>100	78.24
U.S. 76 Florence*	3.16	0.74	0.20	>100	>100	>100	-4.47	4.75	-13.97	64.61	>100	>100	>100	>100	79.59

** Existing condition with TWLTL*

*** Existing condition with Raised Median*

[47] Left-in movements from the immediate upstream intersection to the driveway

Table D-8: Average Travel Time for Right-out[48] Driveway Traffic (Simulation Result)

Corridors	TWLTL	Non-traversable Median		Driveway consolidation		Corner clearance from intersection		Access restriction	
	sec/veh	sec/veh	%**	sec/veh	%**	sec/veh	%**	sec/veh	%**
S.C. 146 Greenville	22*	26	18	13	-41	20	-9	29	30
U.S. 176 Richland	30*	64	>100	14	-54	26	-15	33	8
U.S. 1 Richland #1	23*	81	>100	13	-44	29	23	32	35
U.S.29 Greenville #1	30*	58	96	16	-47	24	-21	35	16
U.S. 29 Greenville #2	29*	55	88	27	-7	18	-38	39	34
U.S. 17 Charleston	-	23*	-	22	-4	25	9	-	-
U.S. 1 Richland #2	23*	67	66	20	-15	26	12	-	-
U.S. 378 Lexington #1	26.7*	77.3	>100	27.9	4.5	28.1	5.2	29.2	9.4
U.S. 378 Lexington #2	11*	36	>100	8	-33	8	-26	18	57
U.S. 76 Florence	10*	22	>100	5	-50	4	-56	17	73

** Existing access management strategies on corridors*

***Percent change (%) compared to existing Condition*

[48] Right-out movements from the driveway to the immediate downstream intersection

Table D-9: Operational Conditions for Right-out[49] Driveway Traffic (Simulation Result)

Corridors	Existing Condition			Percent changes compared to existing condition											
				Non-traversable Median			Driveway consolidation			Corner clearance from intersection			Access restriction		
	Delay (sec/veh)	Stopped Delay (sec/veh)	Number of Stops (sec/veh	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)
S.C. 146 Greenville*	22.81	6.10	1.81	8.33	5.80	8.75	27.23	85.43	6.16	14.92	76.65	-7.85	18.03	67.23	2.28
U.S. 176 Richland*	18.09	7.17	15.65	52.67	16.49	95.52	7.10	12.58	0.27	17.62	29.67	-9.02	-0.39	-6.33	-0.12
U.S. 1 Richland #1*	9.14	2.82	1.17	>100	>100	35.99	23.20	14.74	12.63	>100	>100	35.91	41.20	49.85	21.49
U.S.29 Greenville #1*	14.94	1.89	1.34	5.04	14.99	4.03	1.95	-4.43	-0.54	-1.83	0.07	1.98	-1.83	0.07	1.98
U.S. 29 Greenville #2*	26.64	14.64	1.85	-15.53	-28.39	0.52	3.72	-0.55	1.52	-39.31	-54.95	-21.03	-17.76	-28.74	-0.50
U.S. 17 Charleston**	-	-	-	-	-	-	-3.3	10.2	7.6	46.4	>100	15.7	-	-	-
U.S. 1 Richland #2*	19.77	11.04	1.28	12.72	14.29	22.23	-0.93	-0.27	3.82	-20.36	-47.09	12.73	-	-	-
U.S. 378 Lexington #1*	12.15	2.49	1.47	0.5	-1.2	1.4	5.9	17.3	1.4	4.8	13.3	2.04	0.8	4.4	0.68
U.S. 378 Lexington #2*	15.77	5.20	1.50	-0.83	11.91	-1.96	1.10	-7.58	0.04	19.44	45.78	-2.54	-10.88	-13.59	-4.19
U.S. 76 Florence*	8.78	4.27	0.98	4.10	-0.82	7.76	-14.12	-26.89	-22.55	-5.44	-3.05	54.39	3.87	2.90	8.26

** Existing condition with TWLTL*

*** Existing condition with Raised Median*

[49] Right-out movements from the driveway to the immediate downstream intersection

Table D-10: Average Travel Time for Left-out[50] Driveway Traffic (Simulation Result)

Corridors	**TWLTL**	**Non-traversable Median**		**Driveway consolidation**		**Corner clearance from intersection**		**Access restriction**	
	sec/veh	**sec/veh**	**%****	**sec/veh**	**%****	**sec/veh**	**%****	**sec/veh**	**%****
S.C. 146 Greenville	37*	45	21.5	40	6.8	42	11.5	43	15.2
U.S. 176 Richland	51*	87	>100	60	18.2	52	0.9	60	17.7
U.S. 1 Richland #1	48*	124	>100	52	7.5	64	33.6	62	28.1
U.S.29 Greenville #1	38*	93	>100	38	-1.4	38	0.0	54	42.0
U.S. 29 Greenville #2	60*	103	>100	51	-13.8	43	-28.4	54	-9.0
U.S. 17 Charleston	-	32*	-	32	0	52	-	-	62.5
U.S. 1 Richland #2	59*	90	>100	60	1.0	57	-4.4	-	-
U.S. 378 Lexington #1	41*	118	>100	41.2	1	42	2.7	47	13.9
U.S. 378 Lexington #2	36*	74	100	24	-34.2	34	-6.2	44	20.6
U.S. 76 Florence	22*	67	80.6	26	17.6	33	48.9	59	>100

** Existing access management strategies on corridors*

***Percent change (%) compared to existing Condition*

[50] Left-out movements from the driveway to the immediate downstream intersection

Table D-11: Operational Conditions of Left-out[51] Driveway Traffic (Simulation Result)

Corridors	Existing Condition			Percent changes compared to existing condition											
				Non-traversable Median			Driveway consolidation			Corner clearance from intersection			Access restriction		
	Delay (sec/veh)	Stopped Delay (sec/veh)	Number of Stops (sec/veh	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)	Delay (%)	Stopped Delay (%)	Number of Stops (%)
S.C. 146 Greenville*	35.40	15.98	2.42	7.4	7.5	9.1	70.5	72.5	16.5	51.7	>100	-1.4	53.8	81.5	17.9
U.S. 176 Richland*	43.05	20.70	2.71	14.5	24.7	7.3	18	27.2	3.2	9.1	12.8	1.7	1.8	-3.6	1.71
U.S. 1 Richland #1*	18.69	6.17	1.46	87.4	>100	54.7	18.6	24.9	20	>100	>100	43.4	33.1	46.5	27.1
U.S.29 Greenville #1*	25.50	8.93	2.10	29.6	-7.5	-6	-1.5	-5.18	-0.4	-3.6	-10.3	-2.1	-3.6	-10.3	-2.1
U.S. 29 Greenville #2*	67.88	51.76	2.26	-43.5	-68.10	5.9	-35.5	-46.5	-4.2	-67.3	-82.6	-19.7	-48.7	-68.2	14.2
U.S. 17 Charleston**	-	-	-	-	-	-	-0.6	3.6	6.8	94	>100	5.7	-	-	-
U.S. 1 Richland #2*	25.57	10.53	1.61	55.1	>100	16.5	-6.8	-11.7	-8.3	-6.7	-10.9	5.3	-	-	-
U.S. 378 Lexington #1*	23.4	7.68	1.9	>100	>100	63.2	-6.4	-16.1	-7.4	-6.1	-14.7	-1.6	6	2.2	10.5
U.S. 378 Lexington #2*	28.14	9.73	1.94	14.2	48.3	6.7	1	0.5	1.3	30.2	77.1	-3.2	2.7	7.3	1.8
U.S. 76 Florence*	13.06	4.30	1.29	80.7	>100	33.1	3.1	16.3	-5.9	10.8	45.8	60.9	70.4	>100	23.9

** Existing condition with TWLTL*

*** Existing condition with Raised Median*

[51] Left-out movements from the driveway to the immediate downstream intersection

Table D-12: Operation Conditions for Spot Improvement (Simulation Result)

Traffic Type		*After condition with directional median*				*Before condition without directional median*							
		Travel Time (sec/veh)	*Delay (sec/veh)*	*Stopped Delay (sec/veh)*	*No. of Stops per vehicle*	*Travel Time*		*Delay*		*Stopped Delay*		*No. of Stops*	
						(sec/veh)	*%*	*(sec/veh)*	*%*	*(sec/veh)*	*%*	*Per veh*	*%*
Mainline Traffic		104.2	37.2	17.5	0.8	104.6	0.4	37.5	1	17.6	1	0.8	0.6
Right-in[52] Driveway Traffic	Driveways w/ spot improvement	32.6	3.0	0.0	0.0	32.6	0.1	3.0	1. 5	0.0	-14.7	0.0	0
	Driveways w/o spot improvement	23.3	10.4	4.0	0.4	23.3	0	10.0	-3.7	3.8	-5	0.4	-2.3
Left-in[53] Driveway Traffic	Driveways w/ spot improvement	38.2	7.5	3.2	0.4	37.8	-1.2	7.0	-5.8	2.9	-10.1	0.4	-5.6
	Driveways w/o spot improvement	19.6	5.4	1.2	0.5	19.5	-0.4	5.3	-2.6	1.1	-10.3	0.5	-2.7
Right-out[54] Driveway Traffic	Driveways w/ spot improvement	50.6	19.6	8.9	1.1	51.8	2.4	20.8	6	9.0	0.8	1.2	8.4
	Driveways w/o spot improvement	41.0	17.1	8.0	0.9	41.1	0.3	17.3	1.2	8.1	2.2	0.9	0
Left-out[55] Driveway Traffic	Driveways w/ spot improvement	118.0	39.8	20.8	1.5	71.9	-39.1	29.2	-26.5	12.3	-40.7	1.6	7.8
	Driveways w/o spot improvement	34.8	20.1	9.5	0.9	35.0	0.6	20.4	1.6	9.8	3	0.9	-0.8

[52] Right-in movements from the immediate upstream intersection to the driveway
[53] Left-in movements from the immediate upstream intersection to the driveway
[54] Right-out movements from the driveway to the immediate downstream intersection
[55] Left-out movements from the driveway to the immediate downstream intersection

APPENDIX E ECONOMIC ANALYSIS OF ACCESS MANAGEMENT

Table E-1: Percentage of Businesses that Experience Decrease in Sales Volume after Medians Were Installed

Corridor	Years after median installation					
	Affected business			Business in the control group		
	1	2	3	1	2	3
9	0%	57%	57%	NA	94%	94%
10	8%	8%	8%	100%	100%	100%
11 & 12	50%	50%	25%	100%	100%	100%
13	0%	0%	0%	NA	NA	NA
14	0%	0%	0%	NA	NA	NA
17	4%	-	-	17%	-	-

Table E-2: Profile of the Business Survey Participants (Field Results)

Category		Number (percentage) of responses
Type of corridor		
	Previously Installed Raised Median (PIRM)	24 (31%)
	Recently Installed Raised Median (RIRM)	20 (26%)
	No Raised Median (NRM)	33 (43%)
Type of Business	Destination Business	42 (55%)
	Pass-by Business	35 (45%)
Size of business	Small-sized	36 (37%)
	Large-sized	41 (53%)
Busiest hours of day	Peak	44 (57%)
	Off peak	33 (43%)

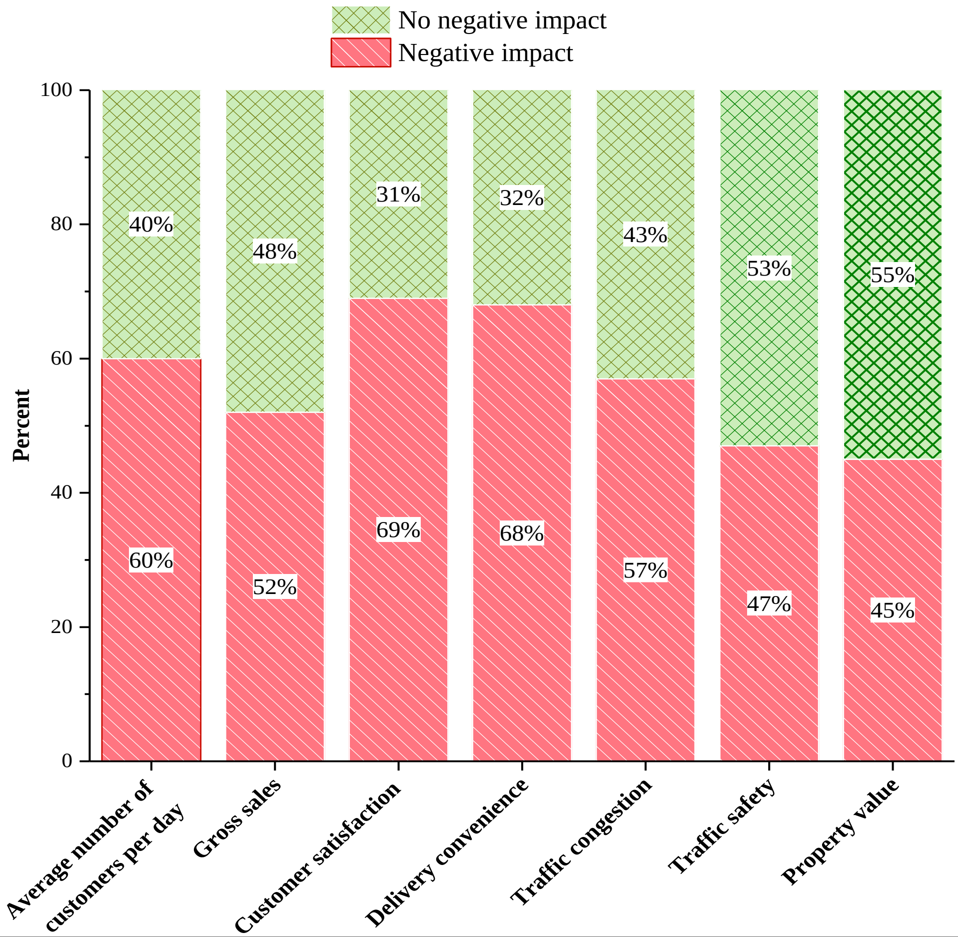


Figure E-1: Responses to the Question Regarding Impact of Raised Medians

Table E-3: Detailed Summary of Response to the Question Regarding Impact of Raised Medians (Field Results)

	Indicated response	Size of business		Type of business		Type of corridor			Busiest hours of day	
		Small-sized	*Large-sized*	*Pass-by*	*Destination*	*PIRM*	*NRM*	*RIRM*	*Peak*	*Off peak*
Average number of customers per day	*Negative impact*	78%	44%	89%	36%	38%	73%	65%	88%	39%
	No negative impact	22%	56%	11%	64%	62%	27%	35%	12%	61%
Gross sales	*Negative impact*	69%	37%	80%	29%	25%	70%	55%	79%	32%
	No negative impact	31%	63%	20%	71%	75%	30%	45%	21%	68%
Customer satisfaction	*Negative impact*	83%	56%	77%	62%	38%	85%	80%	91%	52%
	No negative impact	17%	44%	23%	38%	62%	15%	20%	9%	48%
Delivery convenience	*Negative impact*	86%	54%	83%	57%	46%	79%	80%	100%	45%
	No negative impact	14%	46%	17%	43%	54%	21%	20%	0%	55%
Traffic congestion	*Negative impact*	89%	29%	86%	33%	46%	61%	65%	97%	27%
	No negative impact	11%	71%	14%	67%	54%	39%	35%	3%	73%
Traffic safety	*Negative impact*	94%	5%	74%	24%	46%	45%	50%	100%	7%
	No negative impact	6%	95%	26%	76%	54%	55%	50%	0%	93%
Property value	*Negative impact*	67%	29%	66%	31%	17%	65%	58%	79%	23%
	No negative impact	33%	71%	34%	69%	83%	35%	42%	21%	77%

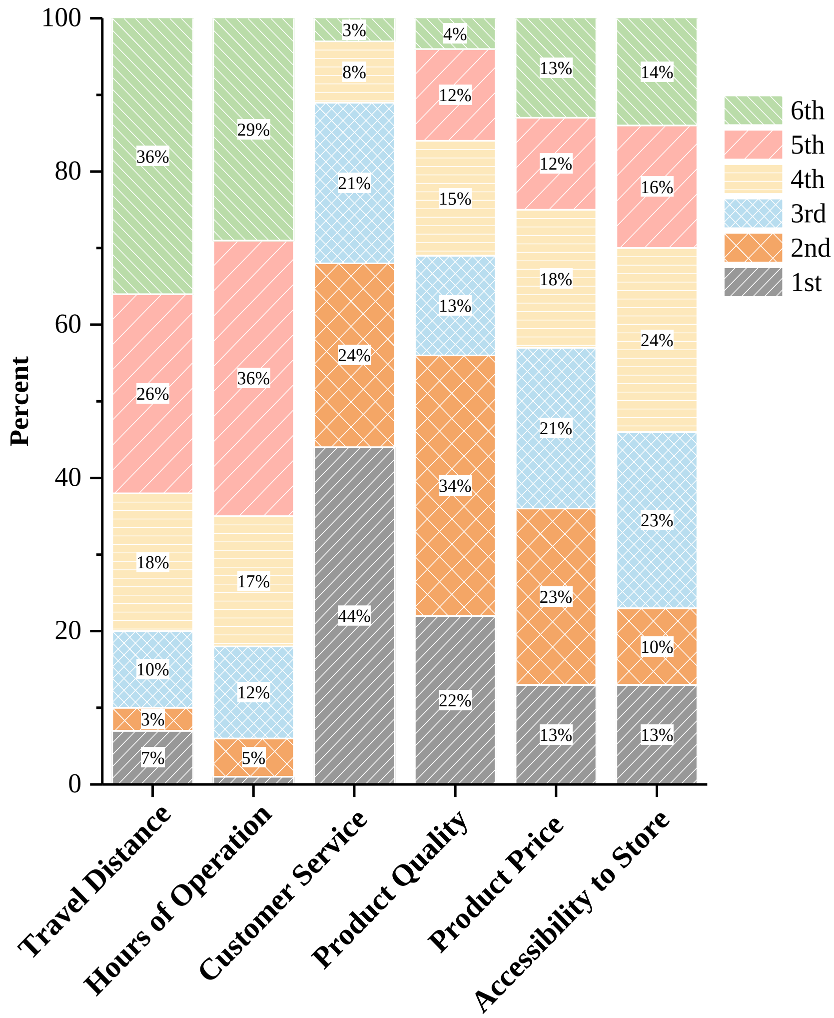


Figure E-2: Responses to Factors Considered by Customers When Selecting a Business (Field Results)

Table E-4: Detailed Summary of Business Responses to Importance of Accessibility to Customers (Field Results)

	Assigned ranking	Size of business		Type of business		Type of corridor			Busiest hours of day	
		Small-sized	*Large-sized*	*Pass-by*	*Destination*	*PIRM*	*NRM*	*RIRM*	*Peak*	*Off-peak*
Accessibility to Stores	*1st*	22%	5%	17%	10%	17%	6%	20%	25%	5%
	2nd	11%	10%	12%	9%	8%	6%	20%	9%	11%
	3rd	25%	22%	23%	24%	13%	27%	30%	24%	23%
	4th	20%	27%	17%	28%	21%	24%	25%	21%	25%
	5th	11%	19%	20%	12%	33%	9%	5%	12%	18%
	6th	11%	17%	11%	17%	8%	28%	0%	9%	18%

Table E-5: Chi-Square Test Results for the Impact of Raised Medians (Field Results)

Factors	Chi-Square test results	Size of business	Type of Business	Type of corridor	Busiest hours of day
Average number of customers per day	Chi-Square test statistic	9.15	22.18	7.48	19.01
	p-value	.002	.000	.024	.000
Gross sales	Chi-Square test statistic	8.29	20.23	11.22	16.67
	p-value	.004	.000	.004	.000
Customer satisfaction	Chi-Square test statistic	6.63	2.07	16.09	13.12
	p-value	.010	**.151**	.000	.000
Delivery convenience	Chi-Square test statistic	9.41	5.88	8.60	26.15
	p-value	.002	.015	.014	.000
Traffic congestion	Chi-Square test statistic	27.82	21.39	1.92	37.40
	p-value	.000	.000	**.383**	.000
Traffic safety	Chi-Square test statistic	61.77	19.54	.11	65.77
	p-value	.000	.000	**.944**	.000
Property value	Chi-Square test statistic	10.77	9.27	12.95	23.81
	p-value	.001	.002	.002	.000

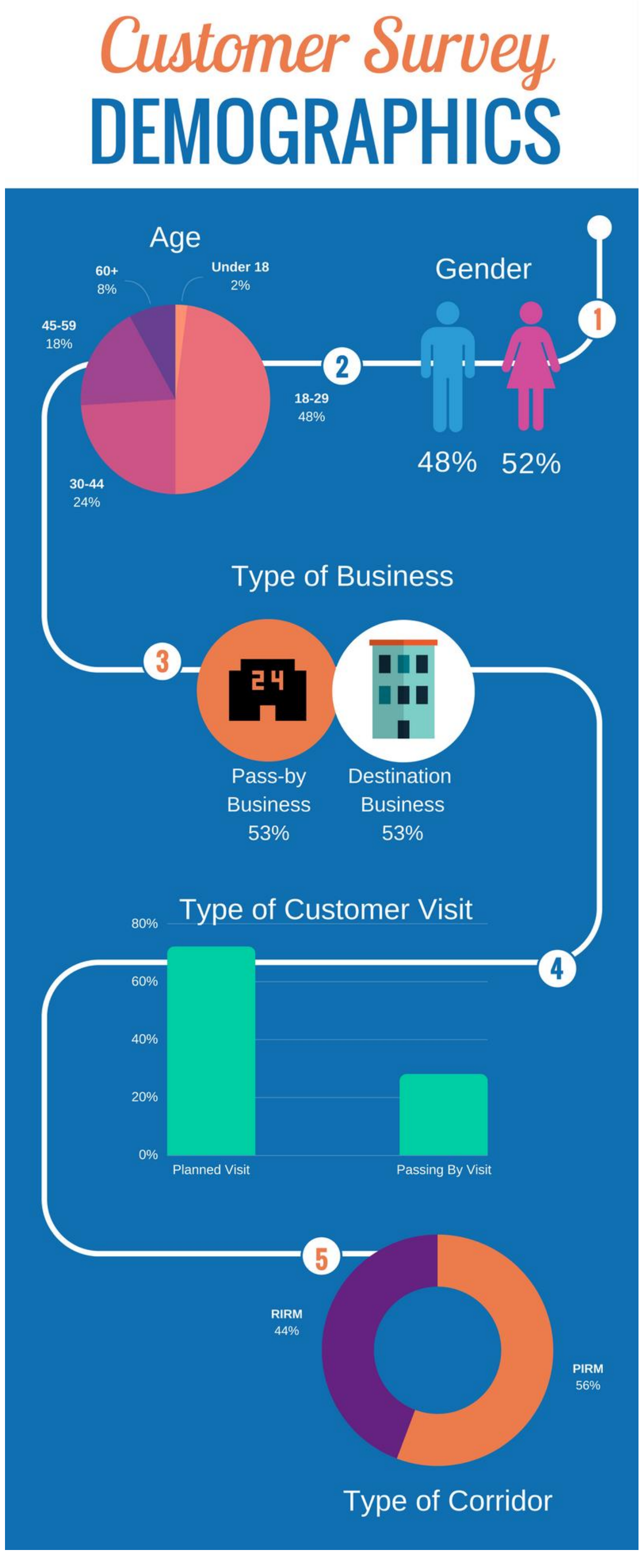


Figure E-3: Profile of the Customer Survey Respondents

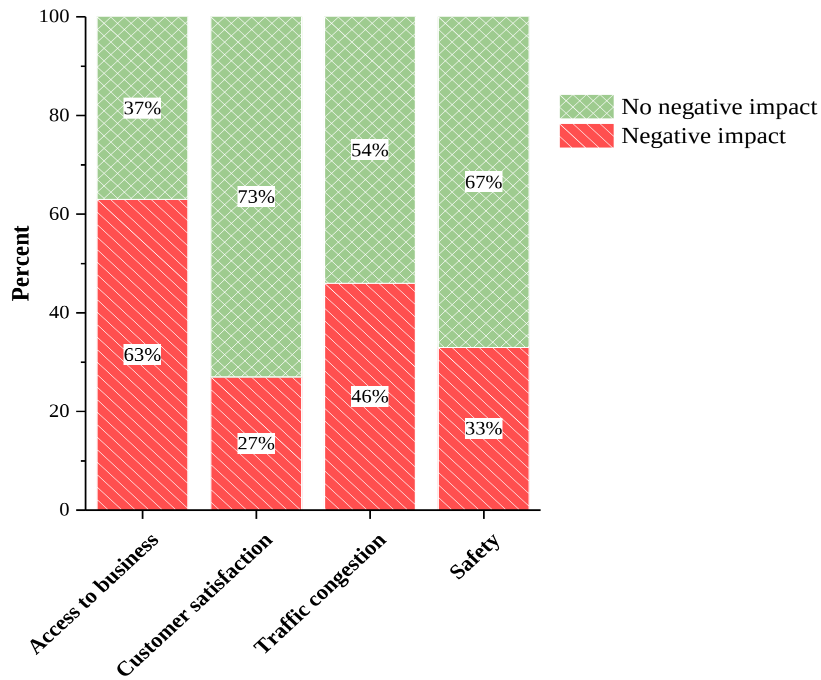


Figure E-4: Responses to the Question Regarding Impact of Raised Medians

Table E-6: Detailed Summary of Response to the Question Regarding Impact of Raised Medians (Field Results)

	Indicated response	Gender of customer		Type of business		Type of customer's visit		Type of corridor	
		Female	*Male*	*Destination*	*Pass-by*	*Planned*	*Passing by*	*PIRM*	*RIRM*
Access to business	*Negative impact*	65%	61%	43%	89%	57%	79%	57%	71%
	No negative impact	35%	39%	57%	18%	43%	21%	43%	29%
Customer satisfaction	*Negative impact*	28%	27%	19%	35%	20%	47%	19%	38%
	No negative impact	72%	73%	81%	65%	80%	53%	81%	69%
Traffic congestion	*Negative impact*	51%	40%	29%	61%	41%	60%	50%	40%
	No negative impact	49%	60%	71%	39%	59%	40%	50%	60%
Traffic safety	*Negative impact*	41%	25%	17%	49%	28%	49%	37%	29%
	No negative impact	59%	75%	83%	51%	72%	51%	63%	71%

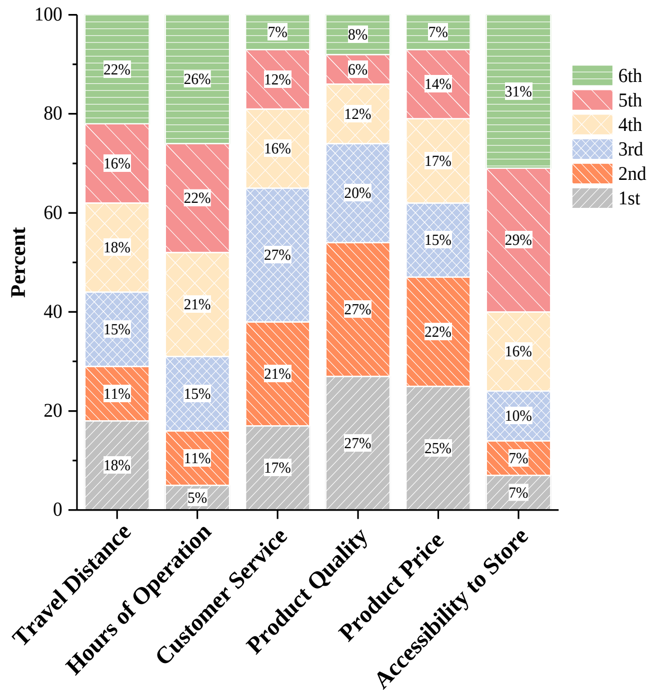


Figure E-5: Responses to Factors Considered by Customers When Selecting a Business (Field Results)

Table E-7: Detailed Summary of Responses to the Question Regarding the Rank of Accessibility (Field Results)

	Ranking	**Gender of customer**		**Type of business**		**Type of customer's visit**		**Type of corridor**	
		Female	*Male*	*Destination*	*Pass-by*	*Planned*	*Passing by*	*PIRM*	*RIRM*
Accessibility to stores	*1st*	8%	6%	4%	10%	7%	7%	9%	5%
	2nd	8%	6%	5%	9%	6%	8%	11%	3%
	3rd	13%	5%	12%	7%	8%	10%	6%	13%
	4th	11%	23%	18%	15%	15%	17%	14%	19%
	5th	32%	26%	28%	30%	28%	29%	23%	36%
	6th	28%	34%	33%	29%	36%	29%	37%	24%

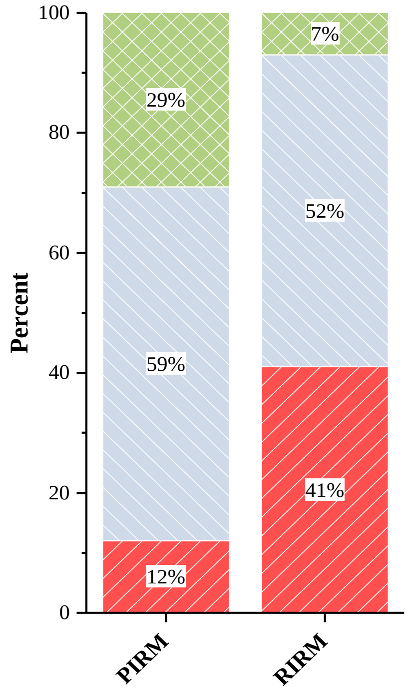


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Table E-8: Responses for PIRM Corridors to the Question Regarding Reasons of Selecting Less Likely and More Likely (Field Results)

Category		Percentage of responses
Reason for more likely	Easier to get to this business	47%
	Take less time to get to this business	11%
	Easier to get to your next destination from this business	42%
Reason for less likely	Less safe to get to this business	46%
	More congestion on the [main road]	54%

Table E-9: Responses for RIRM Corridors to the Question Regarding Reasons of Selecting Less Likely and More Likely (Field Results)

Category		Percentage of responses
Reason for more likely	Safer to get to this business	86%
	Less congestion on [main road]	14%
Reason for less likely	More difficult to get to this business	51%
	Easier to get to another business	16%
	Takes longer to get to this business	33%

Table E-10: Chi-Square Test Results for the Impact of Raised Medians (Field Results)

	Chi-Square test results	**Gender of customer**	**Type of business**	**Type of customer's visit**	**Type of corridor**
Access to business	Chi-Square test statistic	0.50	33.12	7.98	3.70
	p-value	**0.503**	0.000	0.00	0.046
Customer satisfaction	Chi-Square test statistic	0.29	6.86	14.21	9.41
	p-value	**0.864**	0.009	0.000	0.002
Traffic congestion	Chi-Square test statistic	2.34	20.41	6.19	1.82
	p-value	**0.126**	0.000	0.01	**0.177**
Traffic safety	Chi-Square test statistic	6.27	22.97	8.01	1.22
	p-value	0.013	0.000	0.00	**0.269**

Table E-11: Chi-Square Test Results for Assigned Ranks to the Accessibility (Field Results)

	Chi-Square test results	**Gender of customer**	**Type of business**	**Type of customer's visit**	**Type of corridor**
Accessibility to Stores	Chi-Square test statistic	9.945	4.689	1.293	5.569
	p-value	**.077**	**.455**	**.936**	**.350**

Table E-12: Description of Response and Explanatory Variables (Field Results)

Response variable	
Variable abbreviation	***Variable description***
SALE	Indicator variable for the perception of business about the impact of access management on their gross sales: 0 = negative impact; 1 = no negative impact
Explanatory variables	
Business Characteristics	
BUS_TYPE	Indicator variable for type of business: 0 = pass-by business; 1 = destination business
BUS_SIZE	Indicator variable for size of business: 0 = small-sized; 1= large-sized
BUS_EMPL	Indicator variable for number of business employees: 0 = ≤ 25; 1 = > 25
SALE_IND	Indicator variable for sales volume of business: 0 = ≤ 500K; 1= > 500K
ON_PEAK	Indicator variable for busiest hours of day: 0 = if a business has the busiest times occurring during the off-peak hours; 1 = if a business has the busiest times occurring during the peak hours
DRIVW_NO	Number of business driveways
PARK_SPC	Number of dedicated parking spaces to the business
MAJOR	Indicator variable for type access of busiest driveway: 1 = if a business has access from major street; 0 = otherwise
MINOR	Indicator variable for type access of busiest driveway: 1 = if a business has access is from minor street; 0 = otherwise
NEIGHBOR	Indicator variable for type access of business driveway: 1 = if business access is via a neighboring business parking lot; 0 = otherwise
SHARED	Indicator variable for type of business driveway: 0 = the driveway(s) is(are) not shared; 1 = the driveway(s) is(are) shared
Roadway characteristics	
COR_TYPE	Indicator variable for type of corridor: 0 = corridors without raised medians; 1 = corridors with raided medians
AADT	AADT of the corridors that business is located: 0 = ≤ 15,000; 1 = 15,001-50,000; 2 = 50,001-100,000; 3 = >100,000;
SPEED	Posted speed limit along the corridor: 0 = ≤ 45; 1 = 50-60; 2 = ≥65
LANE	Number of lanes along the corridor
Socioeconomic characteristic	
ZIP_HOUS	Number of housing units in the zip code that the business is located: 0 = < 10k; 1 = 10k-20k; 2 = > 20k
ZIP_POP	The population of the zip code that business is located: 0 = < 25k; 1 = 25k-50k; 2 = > 50k
ZIP_ EMPL	Number of employees in the zip code that the business is located : 0 = < 10k; 1 = 10k-20k; 2 = > 20k

Figure E-7: Closing #1 and Two New Conflict Points

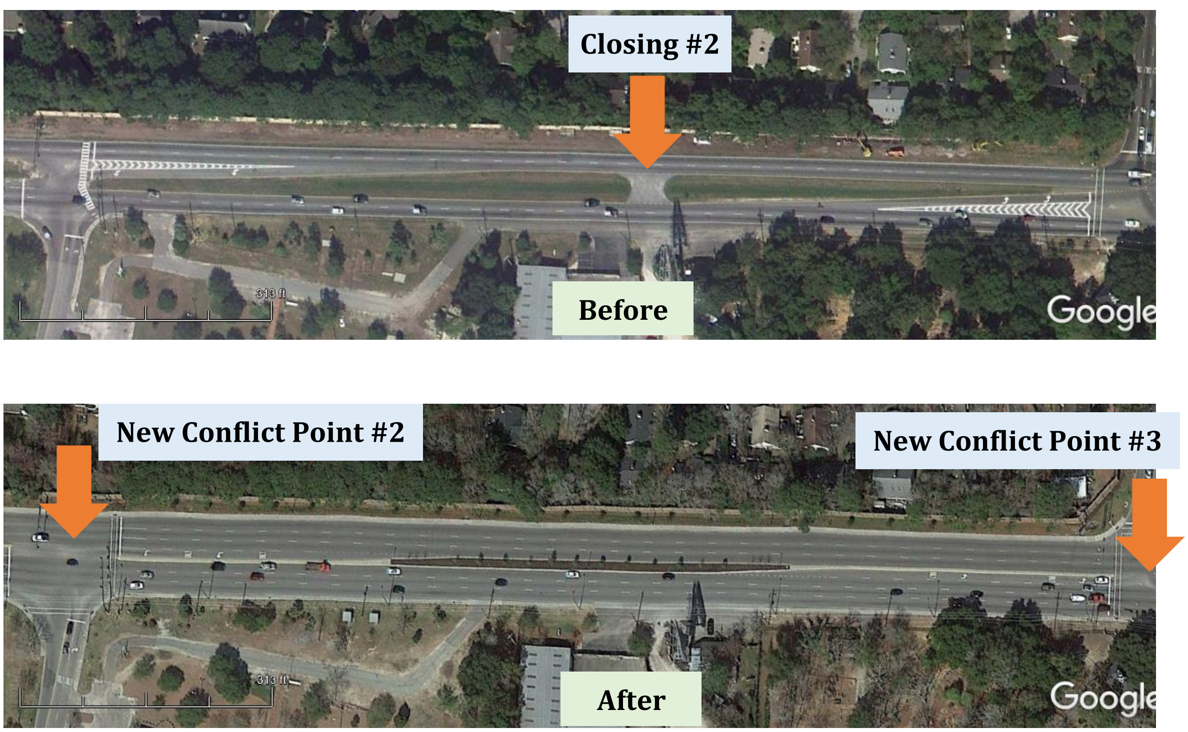

Figure E-8 : Closing #2 and Two New Conflict Points

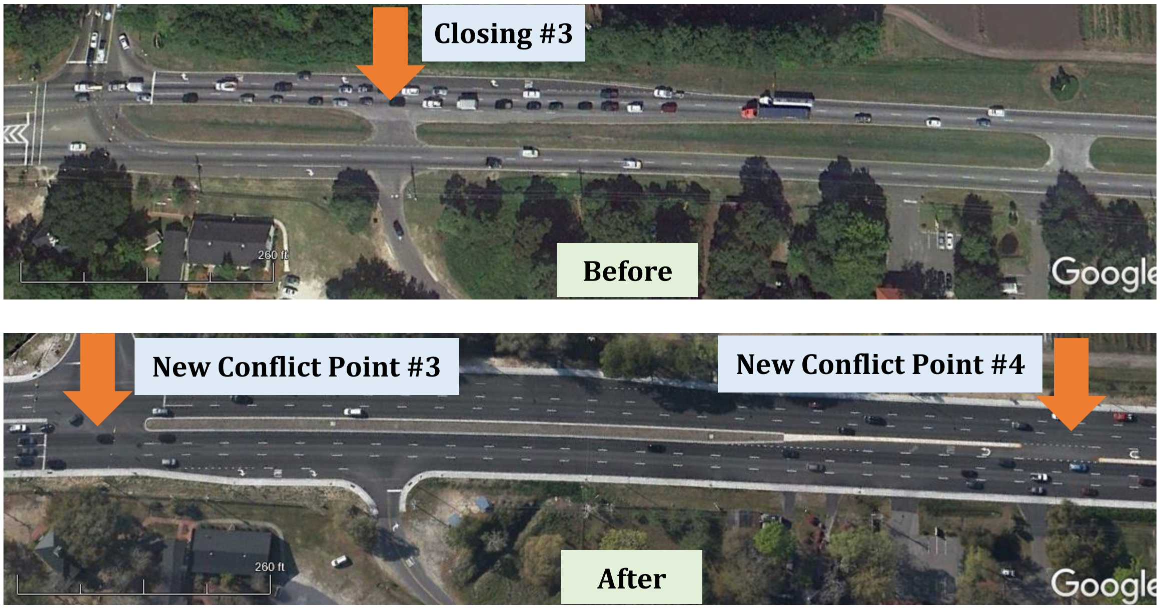

Figure E-9: Closing #3 and Two New Conflict Points

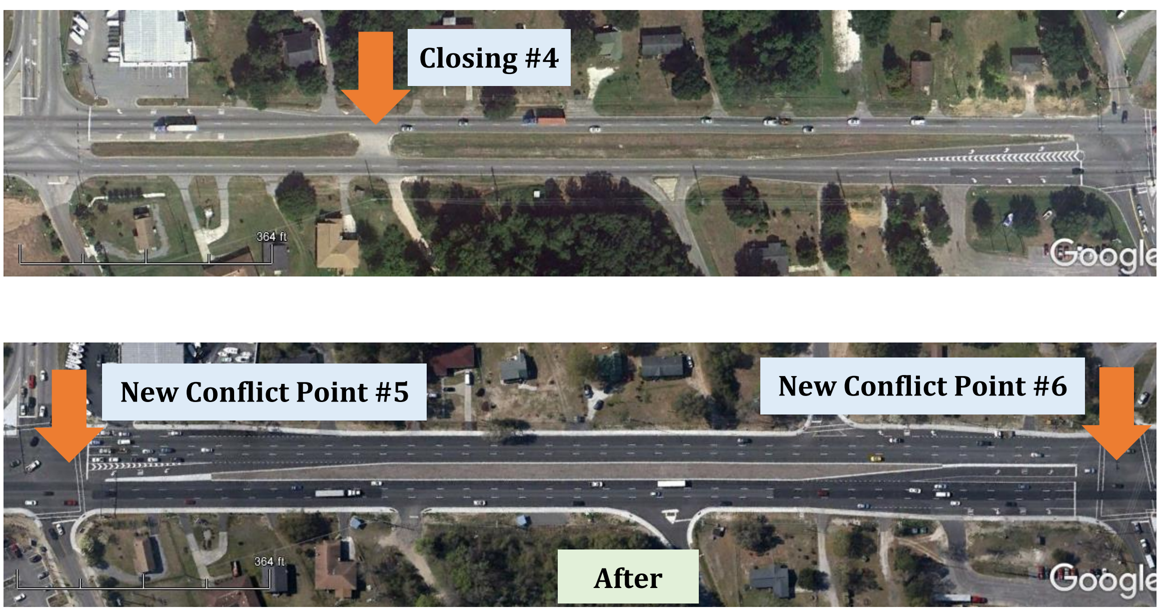

Figure E-10 : Closing #4 and Two New Conflict Points

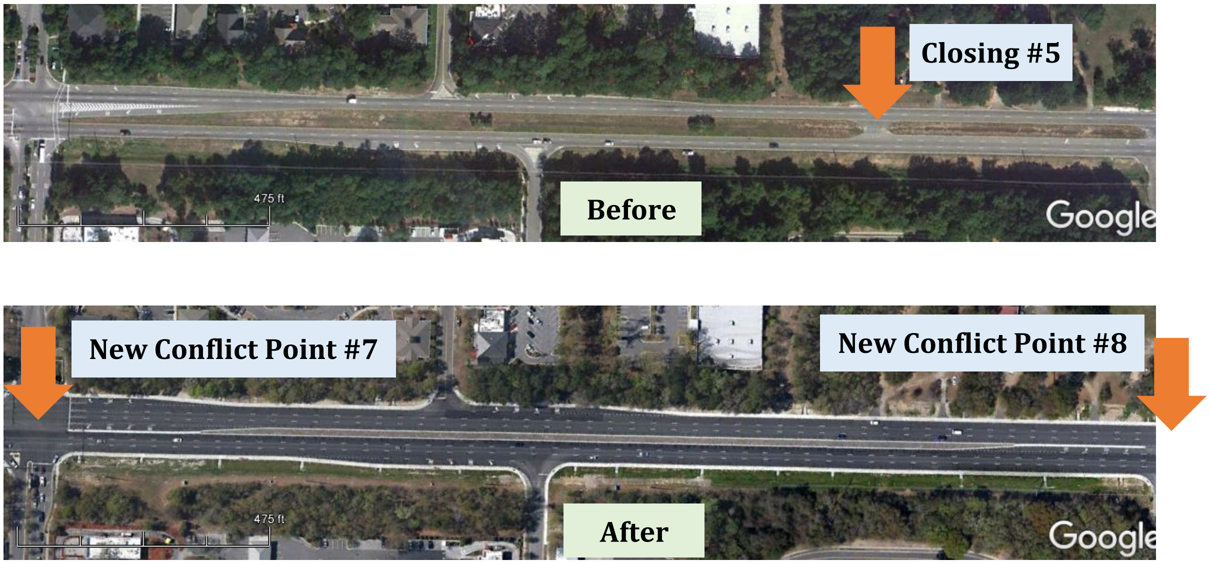

Figure E-11: Closing #5 and Two New Conflict Points

Figure E-12: Closing #6 and Two New Conflict Points

Table E-13: Crash Rates at New Conflict Points Before and After the Construction Period

New conflict point	**RMEV**	
	2011	**2014**
1	0.00	0.00
2	0.47	0.68
3	0.39	1.71
4	0.31	0.09
5	0.16	0.77
6	0.10	0.00
7	0.29	0.21
8	0.10	0.11
9	0.00	0.11
10	0.00	0.11

Table E-14: Results of F-test for Equality in Variances

F-test results	
F-test statistic	0.10
p-value	0.002

Table E-15: Results of t-test to Compare Means of Crash Rates

t-test results	
t-test statistic	-1.10
p-value	0.296

Figure E-13: Closing #1 and New Conflict Points

Table E-16: Crash Rates at New Conflict Points Before and After the Construction Period

New conflict point	**RMEV**	
	2012	**2014**
1	0.54	0.49
2	0	0

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APPENDIX F ONLINE SURVEY QUESTIONNAIRE

This survey is conducted as a part of a South Carolina Department of Transportation (SCDOT) sponsored research project titled "Operational and Economic Analysis of Access Management". It seeks to solicit your input on your state's current access management practices and their effects on nearby businesses. This survey will take approximately 20 minutes to complete. In order to ensure your state's confidentiality, only aggregated results of the survey or non-identifying comments will be published. However, a summary of the survey response will be available upon request.
If you prefer to submit the survey online, please click on following link to enter the survey:
https://www.surveymonkey.com/r/access_mngmnt

General Questions (Question 1-7)
Please provide (X) mark for the selected option

1. In your state, which types of corridor-wide access management techniques are most common?
    - Replacing a two-way left-turn lane (TWLTL) with a raised median
    - Limiting and separating driveways/access points
    - Modifying full driveway access to right-in/right-out
    - Changing signal spacing
    - Restricting driveways in vicinity of intersections
    - Others, please specify________________________________

2. Is any of the following non-conventional access management strategy implemented in your state?
    - Jughandle design
    - Michigan U-turn
    - None of the above
    - Others, please specify________________________________

3. Do you conduct any before-and after study to measure the impact of implemented access management strategies for operational improvement?
    - Yes
    - No

4. If the answer to Question 3 is yes, please specify the measure of effectiveness used in the before-and-after study.
    - Change in mainline average speed
    - Change in mainline travel time
    - Change in intersection queue length
    - Change in driveway stopped delay
    - Others, please specify________________________________

5. Has your state studied the economic impact of access management strategies?
    - Yes
    - No

6. Do your access management design standards consider economic impact?
    - Yes
    - No

7. If the answer of Question 6 is no, is there any interest in doing so?
    - Yes
    - No

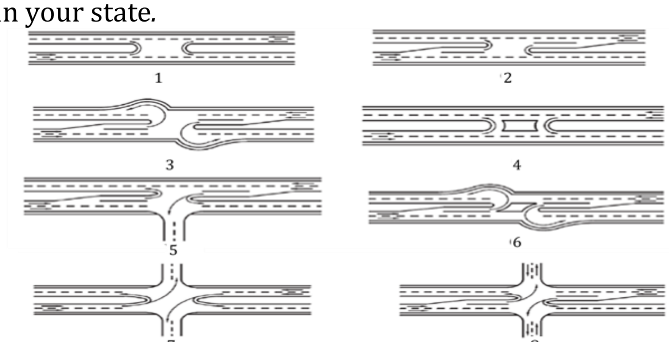
Median Treatment Questions (Question 8-12)

8. Which of the following conditions or guidelines dictate the placement of median openings?
    - Access management manual
    - Traffic impact study
    - Divided highways at all public roads
    - Where a full length left-turn lane can be provided
    - Others, please specify ______________________________

9. Given that appropriate spacing is available, what other factors are important in determining whether a median opening can be placed?
    - High mainline through traffic volume, more than _______________vehicles per day (ADT)
    - Surrounding business types
    - Others, please specify ______________________________

10. Does your agency have any preference regarding full median openings versus directional median openings? If yes, please explain the reason.
    - Yes, please specify_________________________
    - No

11. Please indicate which of the following indirect left-turn treatments are most common in your state.



12. What are the challenges of implementing raised medians with full median opening or directional median opening?

    - Difficulties in retrofitting exiting corridor
    - Opposition from business owners
    - Other, *please specify*______________________________

Questions about Access Points/Driveways (Question 13-15)

The following questions refer to situations where individual driveways are modified to restrict access on a case-by-case basis without a continual raised median.

13. Under which circumstances would a driveway be modified from fully-open access to some form of restricted access (i.e., right-in/right out, right-in, right-out, left-in but no left out, etc.). Please specify threshold values/guidelines if applicable.

    - Driveway is within an intersection's influence area (i.e., distance to intersection is less than 150 feet or less than the required corner clearance distance)
    - Left-turn traffic from driveway interfere with queues from adjacent intersection
    - High mainline through traffic volume, more than ______________vehicles per day (ADT)
    - High driveway density, more than ______________ per mile
    - Posted speed limit (above _____mph)
    - Number of through lanes (____lanes/direction)
    - Other, *please specify*______________________________

14. In instances where the access design of a driveway was modified from fully open to restricted access to improve operational condition, did the condition improve? If the condition did not improve, please explain the reason.
    - Yes
    - No, please explain_______________________

15. What are the challenges in modifying access of an existing driveway?

    - Difficulties in retrofitting exiting driveways without any access restriction
    - Opposition from business owners
    - Other, *please specify*______________________________

Questions about Driveway Density (Question 16-19)

16. In what circumstances do you consider closing a driveway?
    - High mainline through traffic volume, more than ______________vehicles per day (ADT)

- High midblock left-turn volume, more than ______________vehicles per hour
- High driveway density, more than ______________per mile
- High accident frequency, more than ______________
- Traffic impact study
- Other, please specify______________________
- Never closes a driveway

17. Does your agency implement 'driveway closures/consolidation' in order to decrease the driveway density along roadways?
    - Yes
    - No, please explain the reason________________________

18. If the answer to question 17 is 'yes', what are the perceived effects due to the driveway consolidation?
    - Reduced travel time for vehicles in the main corridor
    - Improve minor street traffic operational condition
    - Degrade minor street traffic operational condition
    - Other, please specify_____________________

19. What are the typical challenges in implementing shared driveways?
    - Difficulties in retrofitting exiting condition
    - Difficulties in convincing business owners
    - Other, *please specify*______________________________

<u>Questions about Corner Clearance (Question 20-23)</u>

20. Does your agency close driveways when they are located within the minimum corner clearance distance, according to your policy, from an intersection?
    - Yes
    - No, *please specify the reason*______________________________

21. What is your agency's policy for new constructions that have limited corner clearance?
    - Does not allow driveways within the minimum corner clearance distance
    - Allow if developer provides sufficient access waiver
    - Other, *please specify*_________________

22. What are the thresholds of ADT, driveway volume, etc. that would allow a driveway to remain open even though it is within an intersection's influence area?

    - High mainline through traffic volume, more than ______________vehicles per day (ADT)
    - High driveway volume, more than ______________ vehicles per hour
    - Other, *please specify*_________________

23. What are the challenges in restricting driveways within the minimum corner clearance distance of an intersection?
    - Restriction is difficult in small isolated corner lots
    - Business owners' opposition
    - Other, *please specify*________________

<u>Auxiliary Lane (for an Intersection) Design Questions (Question 24-26)</u>

24. Are right-turn <u>deceleration/acceleration</u> lanes used at non-signalized driveways?
    - Yes
    - No

25. If the answer to question 24 is 'yes', what roadway/traffic conditions necessitate the use of right-turn deceleration/acceleration lane at non-signalized driveways?
    - High mainline through traffic volume, more than _____________vehicles per day (ADT)
    - High driveway volume, more than _____________ vehicles per hour
    - Average queue length (____________)
    - Other, *please specify*________________

26. What are the challenges in installing auxiliary lanes?
    - Implementation difficulties at intersections due to right-of-way limitation
    - Other, *please specify*________________

May we contact you to follow up?

- Yes
- No

Do you wish to receive the summary of survey responses collected from different states?

- Yes
- No

Please provide the following information.

Name:

Organization name:

Department:

Title:

Email:

Phone number:

Thank you for your time in completing this survey.

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APPENDIX G TELEPHONE INTERVIEW QUESTIONNAIRE

This telephone interview is conducted as a part of a South Carolina Department of Transportation (SCDOT) sponsored research project titled "Operational and Economic Analysis of Access Management". It seeks to solicit your input about your state's current access management practices and their effects on nearby businesses. This interview will take approximately 30 minutes, and your response will be kept confidential.

Questions

1. Does your agency have different guiding documents/handbooks/manuals governing access management for i) new roadway construction and ii) retrofit projects?
2. If the answer of Question 1 is 'no', do you have any plan to incorporate guidelines for retrofitting existing corridors?
3. When does your agency attempt to retrofit corridors to incorporate any access management strategy?
   i. When corridors do not conform to the guidelines for access management currently in place in the state
   ii. When the crash rate is high for turning vehicles
   iii. When the traffic operational condition needs to be improved
   iv. Other, please explain ________________________________
4. How a decision is made about closing an access point/driveway?
5. Are frontage roads or service roads encouraged or included in the agency's guidelines for new construction to provide access rather than driveways for each individual business along a roadway?
6. Can business make appeals to have their driveway remain open?
7. Did your state DOT face any lawsuit from business owners after implementing any access management strategy?
8. How has your agency dealt with resistance from business owners on construction or modification of access to their businesses?
9. What type of spot improvements are most common for access management?
10. Did your agency perform a study or fund a study to examine the economic impact of access management strategies?
11. If yes to question 13, is the final report publicly available? If so, where/how can we obtain the report?
12. If yes to question 13, what were the key findings of the study?
13. If yes to question 13, has your agency change your practice/policy/design guidelines as a result of the study's findings?

14. If no to question 13, what are the reasons for not conducting the economic evaluation??
15. Do you have any suggestions for addressing the following specific issue in raised median design for urban arterials?

The requirements for the deceleration and storage of left-turning vehicles may exceed the available length between two intersections. How do you deal with the median treatment under this circumstance? Please explain: ____

APPENDIX H BUSINESS SURVEY FOR ECONOMIC IMPACT OF MEDIAN TO BUSINESSES

(BUSINESS SURVEY ON PIRM AND RIRM CORRIDORS)

The purpose of this survey is to obtain information about the economic effects to your business from access management. Your response to this survey will be instrumental in shaping future traffic access management guidelines in the state of South Carolina. **Your response to this survey will be kept strictly confidential and will not be associated with your business.**

Approximate time to complete survey: 10 minutes

1. Please rank the following factors in ascending order from "1" to "6" (with "1" being the most important) that customers use when selecting a business of your type [19]:

Travel Distance	____________
Hours of Operation	____________
Customer Service	____________
Product Quality	____________
Product Price	____________
Accessibility to Stores	____________

2. Do you believe that the raised median makes the following parameters worse, better, or about the same as before installation [19]?

	Worse	Better	The same
Average number of customers per day	○	○	○
Gross sales	○	○	○
Customer satisfaction	○	○	○
Delivery convenience	○	○	○
Traffic congestion	○	○	○
Traffic safety	○	○	○
Property value	○	○	○

3. How many parking spaces are dedicated to your business [20]?

____________ Spaces

4. If your business has a parking lot, how many driveways does it have [20]?
   - ○ Not Applicable
   - ○ 1

○ 2
○ 3
○ 4
○ 5
○ Greater than 5

5. How do drivers access your parking lot? [20] (Check all that apply)
   ☐ No parking lot exist for business
   ☐ From the major street driveway
   ☐ From the minor street driveway
   ☐ Via a neighboring business parking lot
   ☐ Shared driveway
   ☐ Others (please specify) ______________________________

6. How many customers do you have per day [20]?
   ○ Less than 100
   ○ 100-249
   ○ 250-499
   ○ Greater than 500

7. What is the busiest hour for your business [20]?
   ○ 6 AM to 8 AM
   ○ 11 AM to 6 PM
   ○ 4 PM to 6 PM
   ○ Other time during the day
   ○ Other time during the night

8. What is (are) the busiest day(s) for your business [20]? (Check all that apply)
   ☐ All week
   ☐ Monday
   ☐ Tuesday
   ☐ Wednesday
   ☐ Thursday
   ☐ Friday
   ☐ Saturday
   ☐ Sunday

9. What installation you would like to see made to the adjacent roadway [20]?

☐ Two way left turn lane
☐ Center median
☐ Right turn in and right turn out only
☐ Consolidated driveways

☐ More traffic signals

☐ Others (please explain) ______________________________

10. What percentage of your customers are Planned (i.e., those who intend on stopping), and Impulse (i.e., passer-by customers) [21]?

    Planned ________%

    Impulse ________%

11. Do you have any concern about raised median on adjacent roadway?

____

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Thank you for participating in the survey!

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APPENDIX I BUSINESS SURVEY FOR ECONOMIC IMPACT OF MEDIAN TO BUSINESSES

ECONOMIC IMPACT OF MEDIAN TO BUSINESSES

(BUSINESS SURVEY ON NRM CORRIDORS)

The purpose of this survey is to obtain information about the economic effects to your business from access management. Your response to this survey will be instrumental in shaping future traffic access management guidelines in the state of South Carolina. **Your response to this survey will be kept strictly confidential and will not be associated with your business.**

Approximate time to complete survey: 10 minutes

1. Please rank the following factors in ascending order from “1" to “6" (with “1" being the most important) that customers use when selecting a business of your type [19]:

   Travel Distance ___________

   Hours of Operation ___________

   Customer Service ___________

   Product Quality ___________

   Product Price ___________

   Accessibility to Store ___________

2. Do you believe that the installation of the raised median will make the following parameters worse, better, or about the same as the current situation [19]?

	Worse	Better	The same
Average number of customers per day	○	○	○
Gross sales	○	○	○
Customer satisfaction	○	○	○
Delivery convenience	○	○	○
Traffic congestion	○	○	○
Traffic safety	○	○	○
Property value	○	○	○

3. How many parking spaces are dedicated to your business [20]?

_______________ Spaces

4. If your business has a parking lot, how many driveways does it have [20]?
   - ○ Not Applicable
   - ○ 1
   - ○ 2
   - ○ 3
   - ○ 4
   - ○ 5
   - ○ Greater than 5

5. How do drivers access your parking lot [20]? (Check all that apply)
   - ☐ No parking lot exist for business
   - ☐ From the major street driveway
   - ☐ From the minor street driveway
   - ☐ Via a neighboring business parking lot
   - ☐ Shared driveway
   - ☐ Others (please specify) ________________________________

6. How many customers do you have per day [20]?
   - ○ Less than 100
   - ○ 100-249
   - ○ 250-499
   - ○ Greater than 500

7. What is the busiest hour for your business [20]?
   - ○ 6 AM to 8 AM
   - ○ 11 AM to 6 PM
   - ○ 4 PM to 6 PM
   - ○ Other time during the day
   - ○ Other time during the night

8. What is (are) the busiest day(s) for your business [20]? (Check all that apply)
   - ☐ All week
   - ☐ Monday
   - ☐ Tuesday
   - ☐ Wednesday
   - ☐ Thursday
   - ☐ Friday
   - ☐ Saturday
   - ☐ Sunday

9. What installation you would like to see made to the adjacent roadway [20]?

☐ Two way left turn lane

☐ Center median

☐ Right turn in and right turn out only

☐ Consolidated driveways

☐ More traffic signals

☐ Others (please explain)

____

10. What percentage of your customers are Planned (i.e., those who intend on stopping), and Impulse (i.e., passer-by customers) [21]?

Planned __________%

Impulse __________%

11. Do you have any concern about raised median on adjacent roadway?

____

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Thank you for participating in the survey!

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APPENDIX J CUSTOMER SURVEY FOR ECONOMIC IMPACT OF MEDIAN TO BUSINESSES

(CUSTOMER SURVEY ON PIRM CORRIDORS)

The purpose of this survey is to obtain information about the economic effect of raised medians to businesses. Your response to this survey will be instrumental in shaping future traffic access management design guidelines in the state of South Carolina. **Your response to this survey is anonymous and will be kept strictly confidential.**

Approximate time to complete survey: less than 5 minutes

1. Your age:
   ○ Under 18
   ○ 18 - 29
   ○ 30 - 44
   ○ 45 - 59
   ○ 60+

2. Your gender:
   ○ Male
   ○ Female

3. Please rank the following six factors from “1" to “6" (with “1" being the most important) when selecting a business of this type [19]:
   Travel Distance ____________
   Hours of Operation__________
   Customer Service ___________
   Product Quality ____________
   Product Price ______________
   Accessibility to Store _________

4. Did you plan to come to this business or stop here because you were passing by [19]?
   ○ Planned
   ○ Passing by

5. How often do you visit this business?
   ○ Daily
   ○ Weekly
   ○ Monthly
   ○ Once in a while
   ○ It is the first time

6. Are you aware that there is a raised median in front of this business (which prohibits left turns from [main road] into the business) [19]?
   ○ Yes
   ○ No

7. When leaving this business, will you have to go the opposite way than you would like and make a U-turn (or series of right turns) [19]?
   ○ Yes
   ○ No

8. Do you believe you will more likely or less likely to visit this business if the raised median is not there on [main road] [19]?
   ○ Less likely
   ○ More likely
   ○ Stay about the same

9. If you answered less likely to Question 8, why [19]?
   ☐ Less safe to get to this business
   ☐ More congestion on the [main road]
   ☐ Others (please specify) ____________________

10. If you answered more likely to Question 9, why [19]?
   ☐ Easier to get to this business
   ☐ Take less time to get to this business
   ☐ Easier to get to your next destination from this business
   ☐ Others (please specify) ____________________

11. Does the raised median make the following issues better, worse, or about the same [19]?

	Worse	*Better*	*The same*
Access to business	○	○	○
Customer satisfaction	○	○	○
Traffic congestion	○	○	○
Traffic safety	○	○	○

12. Do you have any comment regarding raised medians [19]?

Thank you for participating in the survey!

APPENDIX K CUSTOMER SURVEY FOR ECONOMIC IMPACT OF MEDIAN TO BUSINESSES

CUSTOMER SURVEY ON RIRM CORRIDORS)

The purpose of this survey is to obtain information about the economic effect of raised medians to businesses. Your response to this survey will be instrumental in shaping future traffic access management design guidelines in the state of South Carolina. **Your response to this survey is anonymous and will be kept strictly confidential.**

Approximate time to complete survey: less than 5 minutes

1. Your age:
   ○ Under 18
   ○ 18 - 29
   ○ 30 - 44
   ○ 45 - 59
   ○ 60+
2. Your gender:
   ○ Male
   ○ Female
3. Please rank the following six factors from “1" to “6" (with “1" being the most important) when selecting a business of this type [19]:
   Travel Distance ____________
   Hours of Operation__________
   Customer Service ___________
   Product Quality ____________
   Product Price ______________
   Accessibility to Store _________
4. Did you plan to come to this business or stop here because you were passing by [19]?
   ○ Planned
   ○ Passing by
5. How often do you visit this business?
   ○ Daily
   ○ Weekly
   ○ Monthly
   ○ Once in a while
   ○ It is the first time
6. Did you visit this business prior to the installation of the raised median [19]?
   ○ Yes
   ○ No

If you answered “*No*” to Question 6, please proceed to Question 11.

7. Does the raised median force you to go the opposite way than you would like and make a U-turn (or series of right turns) [19]?
○ Yes
○ No

8. With the raised median, do you believe you are now more likely or less likely to visit this business or is it about the same [19]?
○ Less likely
○ More likely
○ Stayed about the same

9. If you answered "*less likely*" to Question 8, why [19]?
☐ More difficult to get to this business
☐ Takes longer to get to this business
☐ Easier to get to another business
☐ Others (please specify) ____________________

10. If you answered "*more likely*" to Question 8, why [19]?
☐ Safer to get to this business
☐ Less congestion on [main road]
☐ Others (please specify) ____________________

11. Does the raised median make the following issues better, worse, or about the same [19]?

	Worse	*Better*	*The same*
Access to business	○	○	○
Customer satisfaction	○	○	○
Traffic congestion	○	○	○
Traffic safety	○	○	○

12. Do you have any comment regarding raised medians [19]?

Thank you for participating in the survey!

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