Surrogate Effects

Generally, before and after responses were negative when asked if roadway modifications would improve safety; however, there was a significant change in attitude from the before to after period which seems to indicate that perceptions improved following actual median installation, as opposed to the “what if” questions on expectations of businesses on comparison sites. When looking at individual site pairs, every pair showed that perceptions of safety increased or stayed the same after median installation.

A total of 62% of treatment respondents at treatment sites ranked accessibility as the 4th, 5th, or 6th consideration of customers for their business. Only 15% of businesses at treatment corridors actually ranked accessibility as the number one consideration of customers. The top three customer considerations when choosing a business that were indicated by respondents at treatment sites were *1)* Customer Service - 33%, *2)* Product Quality – 27%, and *3)* Product Price – 16%.

When asked if the median installation would make various parameters better, worse, or stay the same, a very high percentage of respondents agreed that traffic congestion and safety would improve or stay the same. It appears that the perceived effect on the number of customers per day was much worse at comparison sites than treatment sites, indicating that the median did not affect customers as bad as it was originally thought. Accessibility to store was perceived to be much worse between comparison and treatment respondents; however, the perception at treatment sites was much better than comparison sites indicating again that the median did not affect customers as bad as originally thought.

In general, the survey data indicates a significant and positive change in respondent’s perceptions between comparison and treatment sites. In spite of the overall negative reactions to a proposed median installation, survey data from the businesses represented here appear to support a more favorable perception after installation occurs.

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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.

State DOTs Online Survey and Phone Interviews

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.

Operational Impact Assessment of Access Management

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.

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[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

Table of Contents

Some pages and all Appendices have been removed to reduce the overall size of the document, but they can be made available upon request.

LIST OF TABLES

LIST OF FIGURES

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.

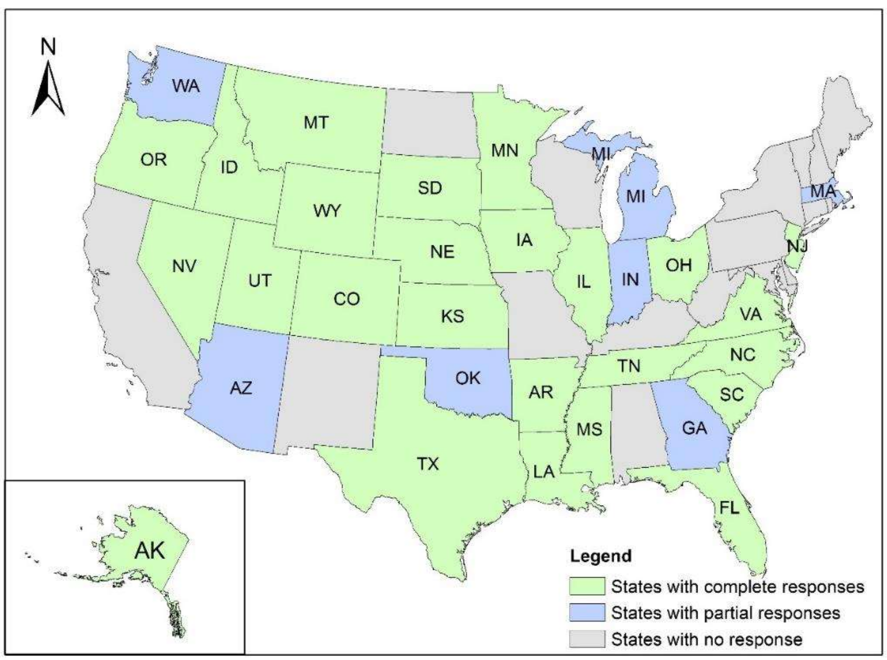

Figure 2-1: Online Survey Participants for Access Management Study

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].

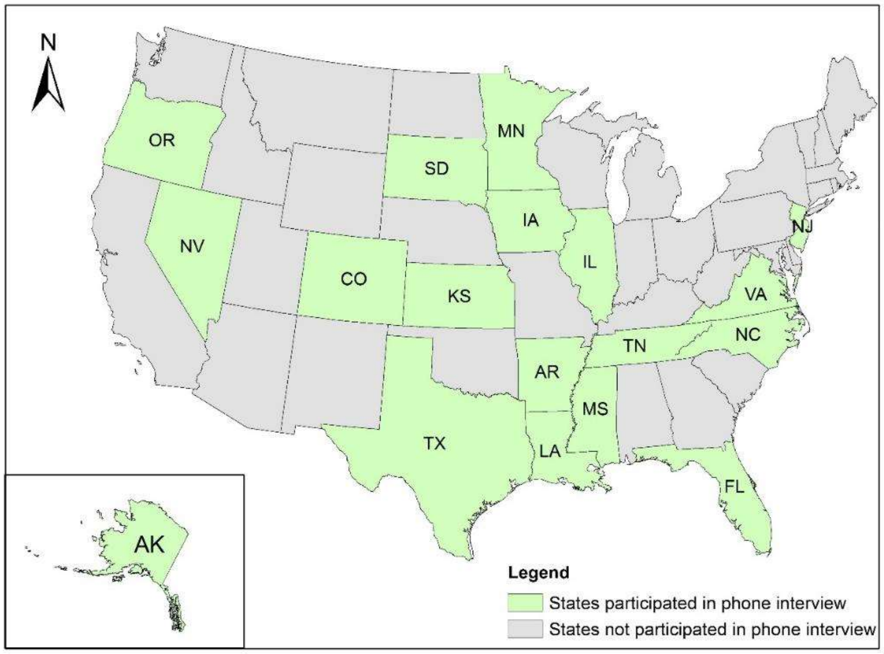

Figure 2-2: Phone Interview Participants for Access Management Study

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.

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.

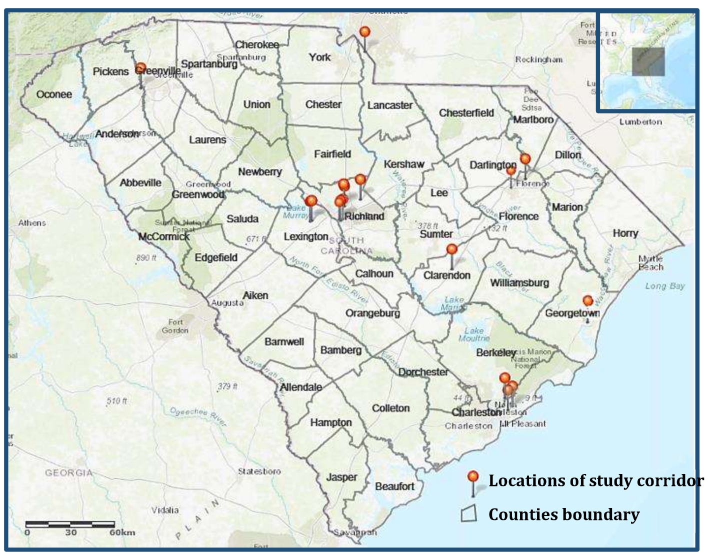

Figure 3-1: Locations of Study Corridors

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.

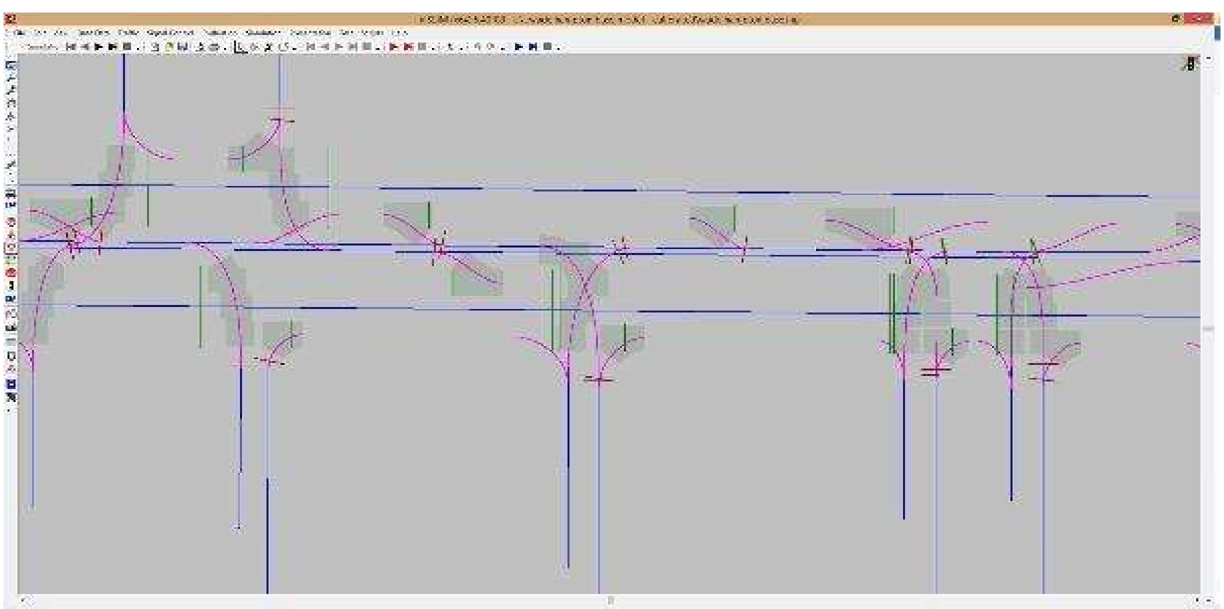

Figure 3-3: TWLTL Modeling using Priority Rules and Conflict Areas

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.

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[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

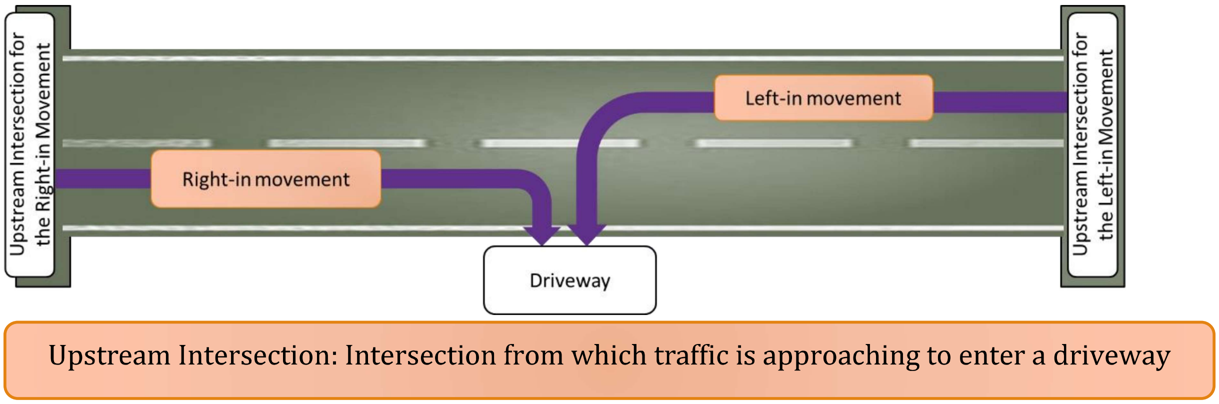

Figure 3-4: Right-in[16] and Left-in[17] Driveway Movements

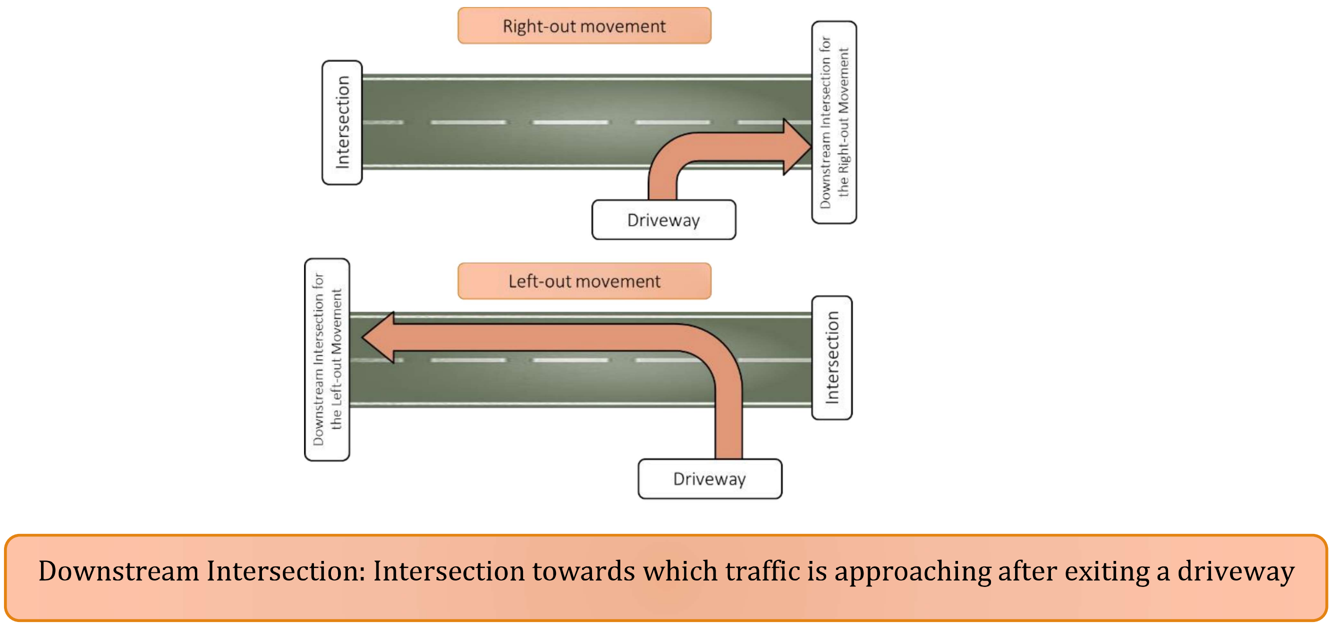

Figure 3-5: Right-out[14] and Left-out[15] Driveway Movements

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.

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

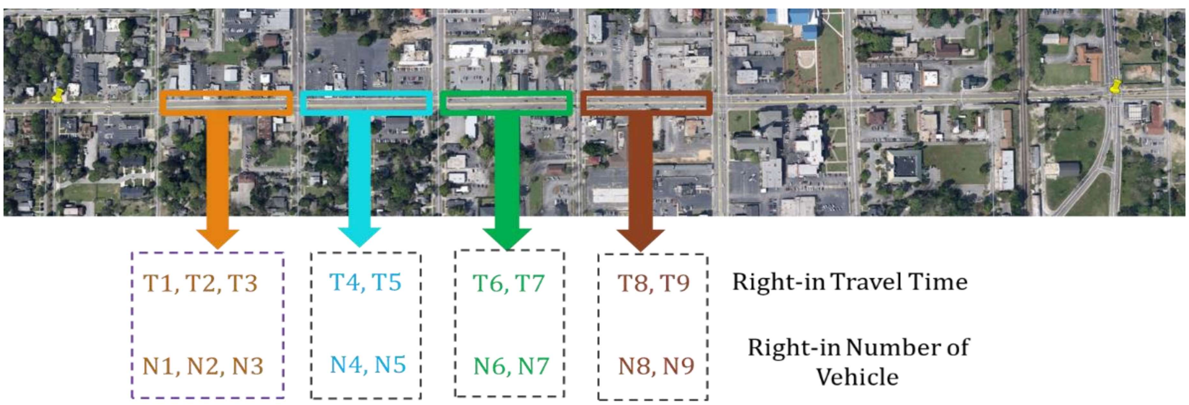

Figure 3-6: Right-in[18] Travel Time for U.S. 76 Florence

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].

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

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.

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

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

The degree of freedom is calculated as follows.

$$df = (r-1)(c-1) \quad \textit{Eq. 3-6}$$

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 $X = (x_1, x_2, \dots, x_n)$ 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].

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

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:

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

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].

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

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].

$$\begin{aligned}&\Pr[y=1 \mid z=1]-\Pr[y=1 \mid z=0] \\ &= F(\beta' X+\alpha z \mid z=1)-F(\beta' X+\alpha z \mid z=0) \\ &= F[\beta' X+\alpha]-F[\beta' X]\end{aligned} \qquad \textit{Eq. 3-11}$$

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.