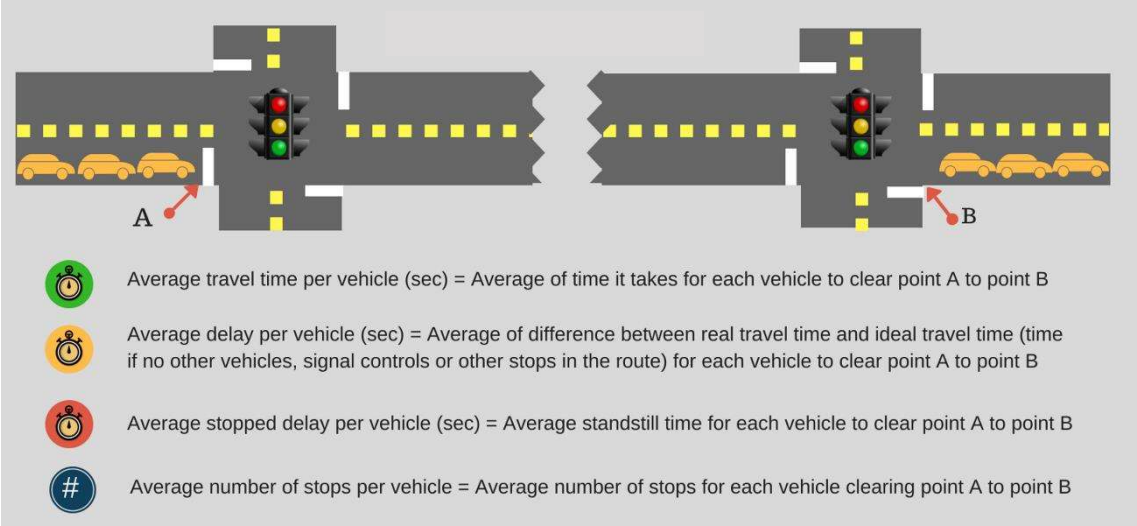

Figure 4-1: Measures of Effectiveness for Operational Analysis

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

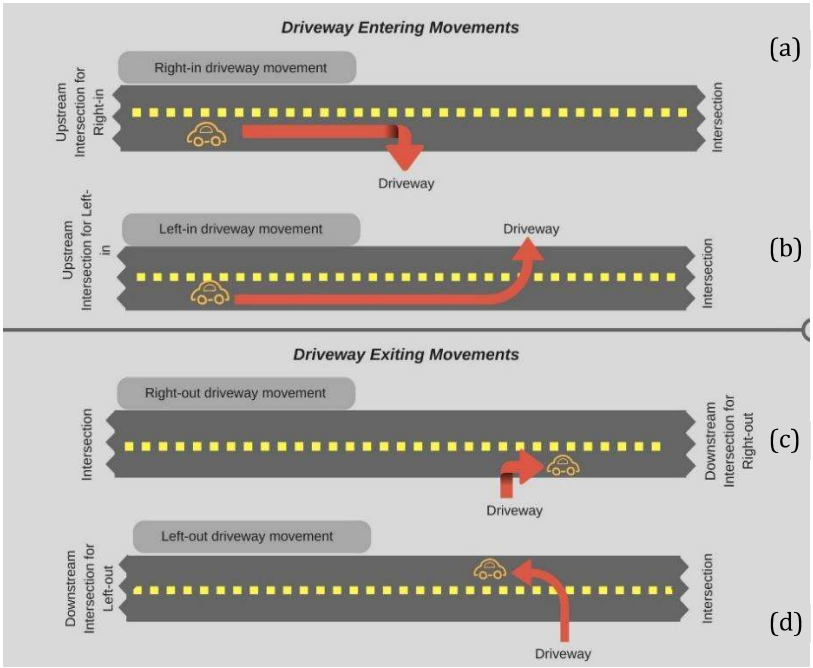

Figure 4-2: Driveway Entering and Exiting Movements

[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.

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].

APPENDIX C SELECTED CORRIDORS AND ACCESS CONTROL STRATEGIES

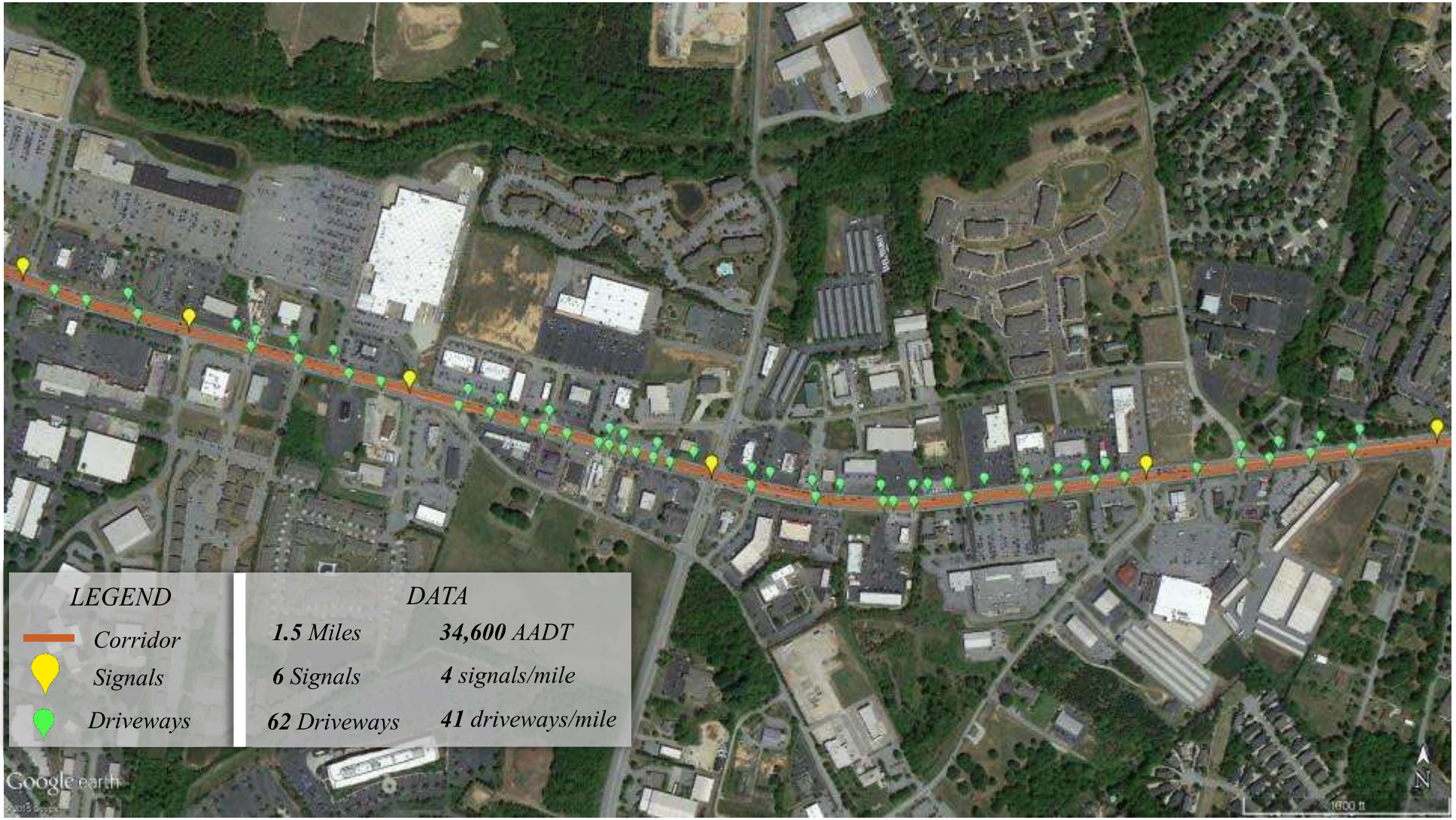

Figure C-1: S.C. 146 Greenville Woodruff Road

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

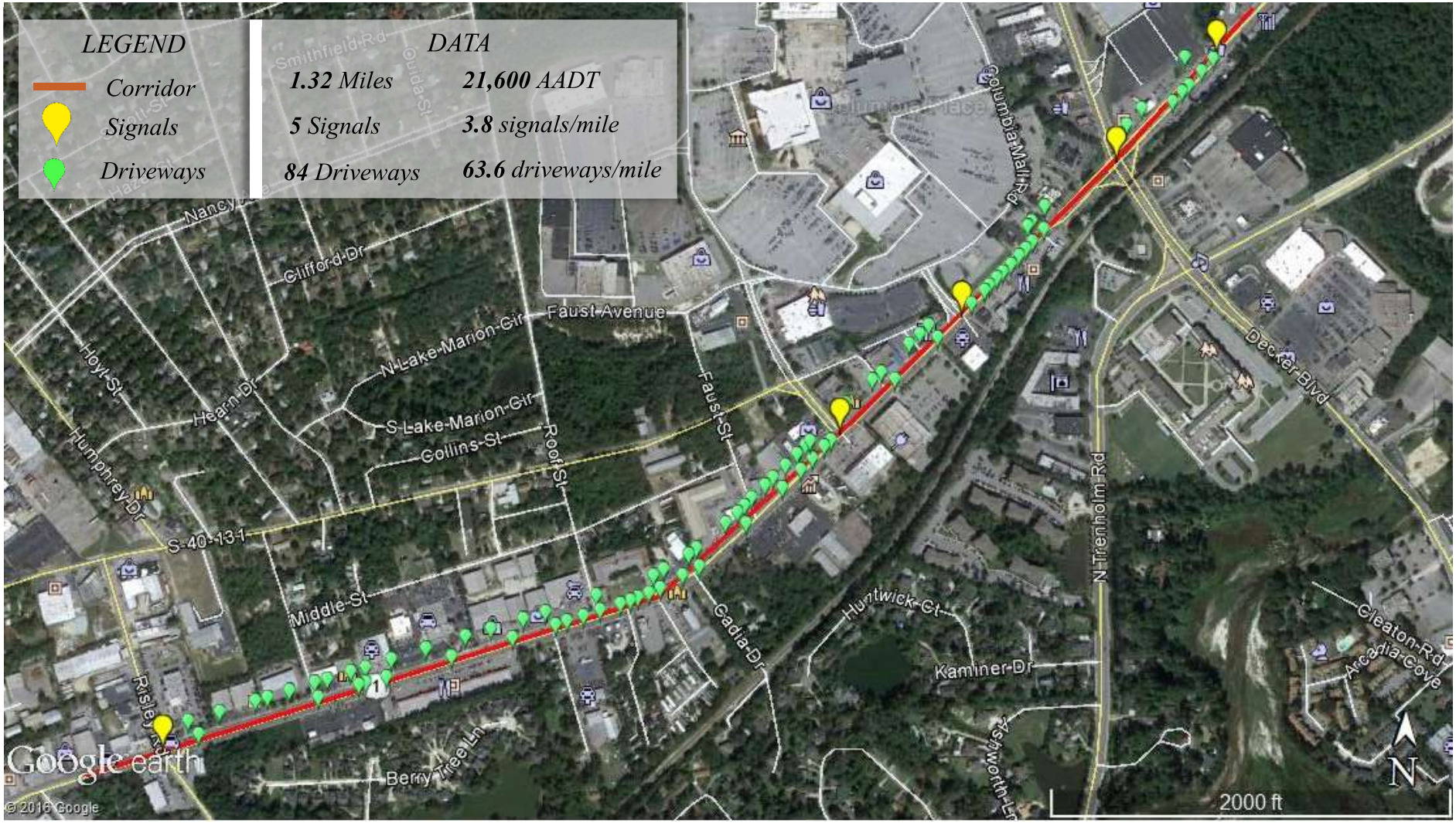

Figure C-3: U.S. 1 Richland #1 (Two Notch Road) Corridor

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

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

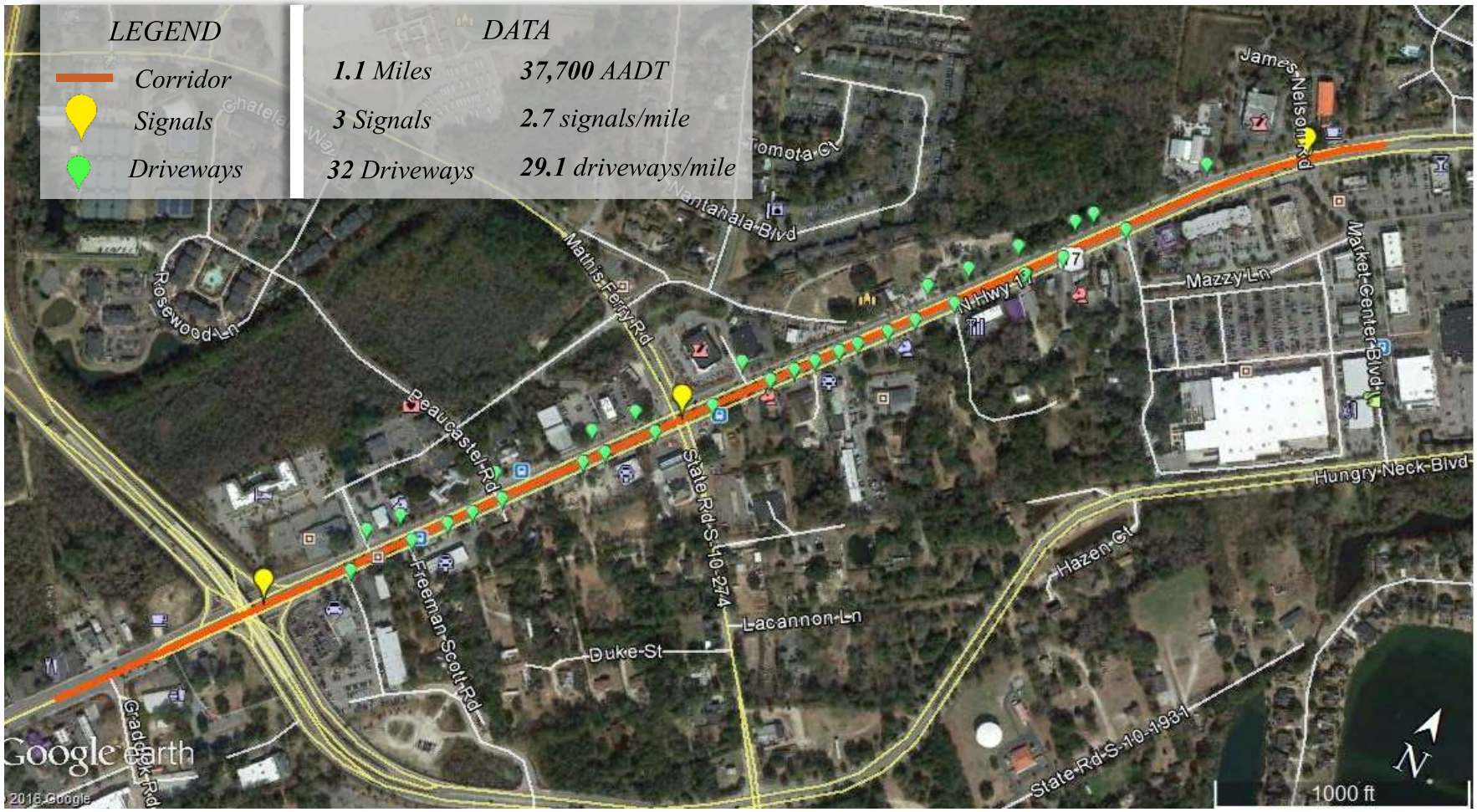

Figure C-6: U.S. 17 Charleston Corridor

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

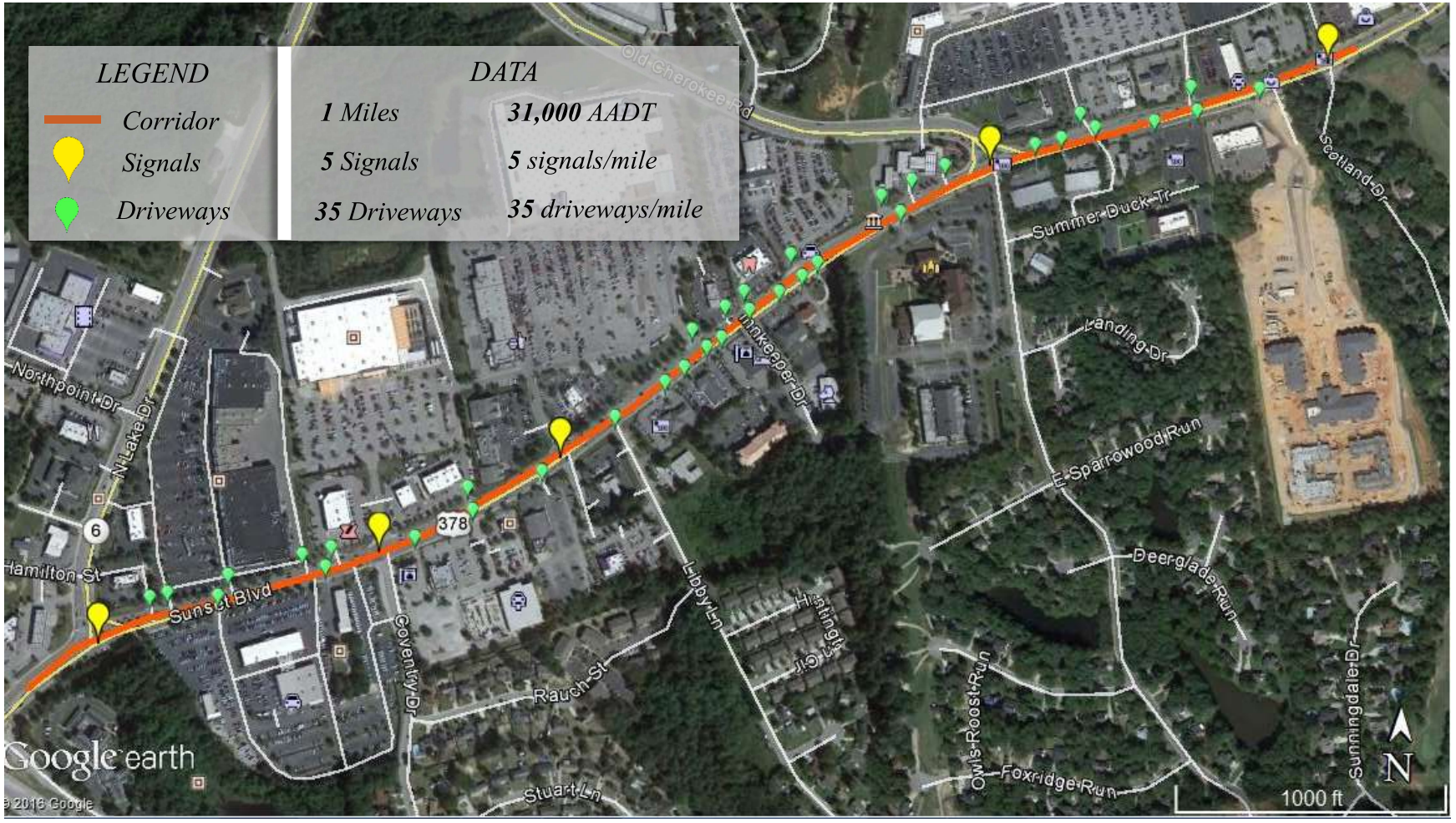

Figure C-8: U.S. 378 Lexington #1 (Sunset Blvd) Corridor

I339

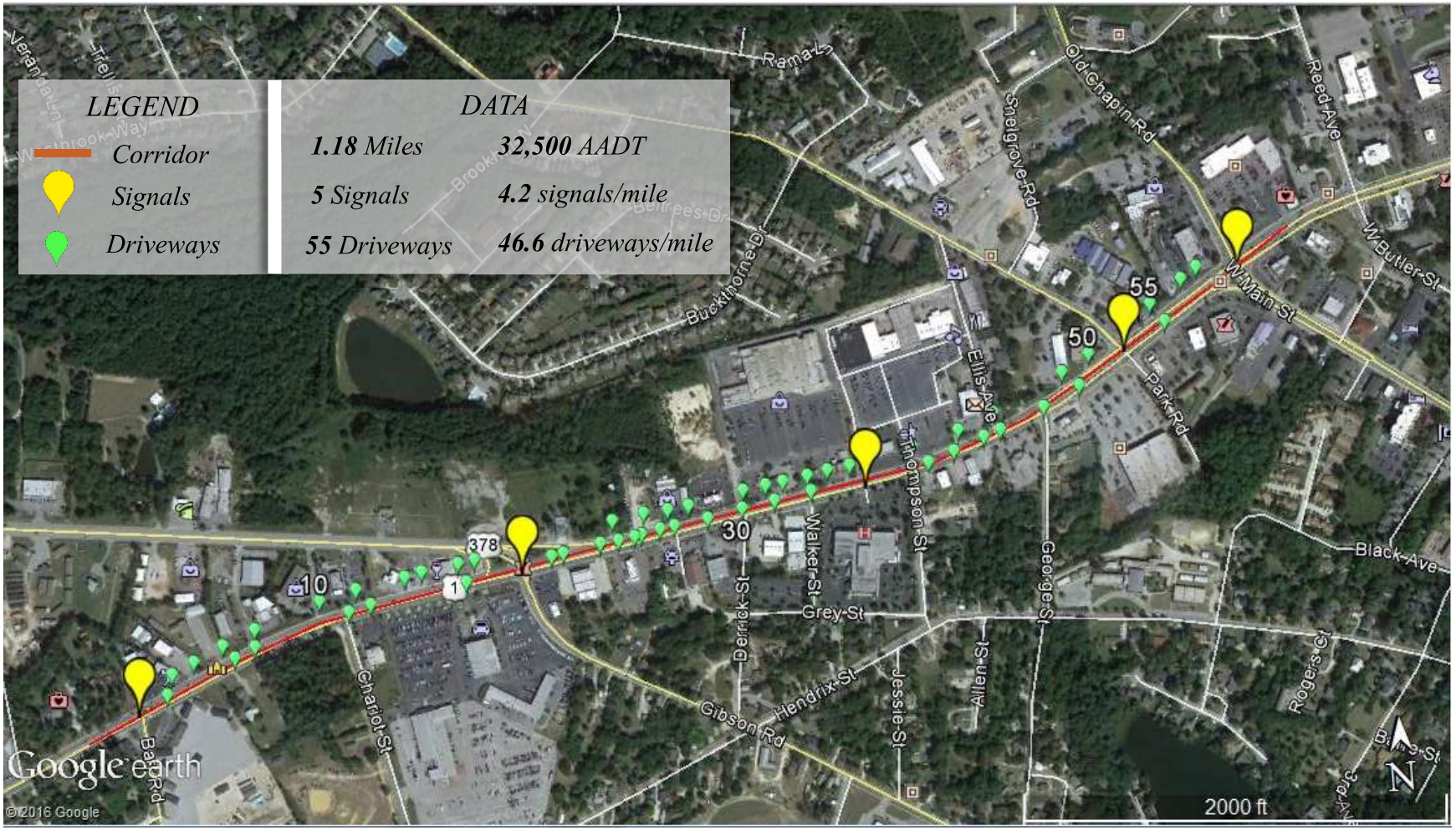

Figure C-9: U.S. 378 Lexington #2 (West Main Street) Corridor

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

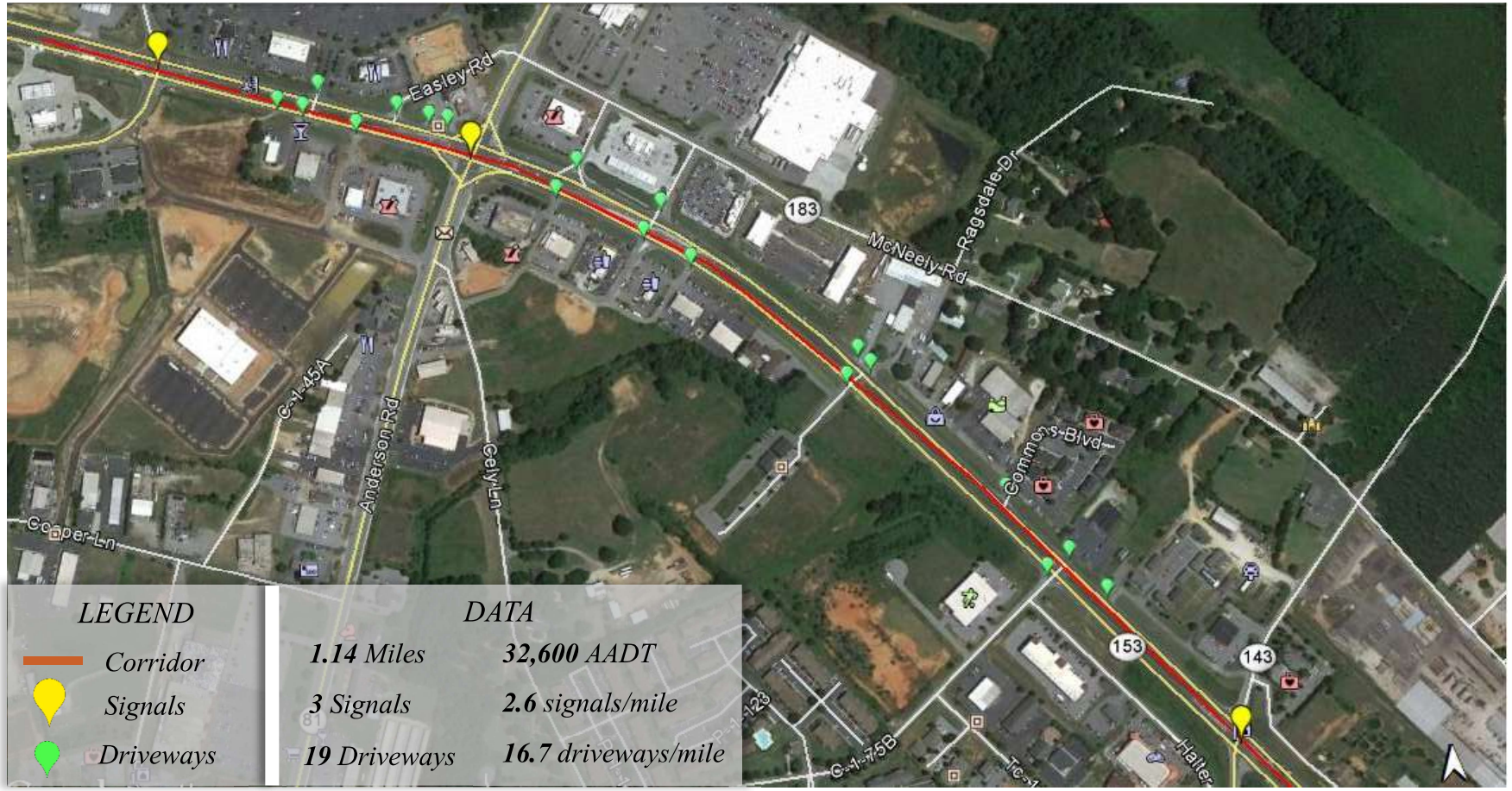

Figure C-11: S.C. 153 Powdersville Corridor

REFERENCES FOR THE REPORT AND APPENDICES

[1] "Access Management Manual 2014, Second Edition," 2014.

[2] S. M. Khan, M. Chowdhury, K. Dey, and N. Huynh, "Traffic Access Decision for Multilane Urban Arterial Considering Both Business and Operational Interests," in *TRB 96th Annual Meeting Compendium of Papers*, 2017.

[3] "Access Management in the Vicinity of Intersections-FHWA-SA-10-002," 2010.

[4] D. J. Plazak and R. R. Souleyrette, "Process to Identify High Priority Corridors for Access Management Near Large Urban Areas in Iowa Using Spatial Data," in *Proceedings of the 2003 Mid-Continent Transportation Research Symposium*, 2003.

[5] M. A. Chowdhury, N. Derov, P. Tan, and A. Sadek, "Prohibiting left-turn movements at mid-block unsignalized driveways: Simulation analysis," *J. Transp. Eng.*, vol. 131, no. April, pp. 279–285, 2005.

[6] H. Zhou, J. Lu, X. Yang, S. Dissanayake, and K. Williams, "Operational Effects of U-Turns as Alternatives to Direct Left Turns from Driveways," *Transp. Res. Rec.*, vol. 1796, no. 1, pp. 72–79, 2002.

[7] R. Lyles, B. Malik, A. Chaudhry, Abu-Lebdeh Ghassan, and M. A. Siddiqui, "An Evaluation of Right-Turn-In/Right-Turn-Out Restrictions in Access Management," 2009.

[8] S. M. Khan, M. A. Chowdhury, K. Brunk, S. Shiri, N. Huynh, and J. Mithcell, "Operational and Economic Impacts of Access Management - Recent Perspectives of State DOTs," in *Proceeding of 97th Annual Meeting of the Transportation Research Board*, 2018.

[9] 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.

[10] "SC Average Annual Daily Traffic," 2015. [Online]. Available: http://www.scdot.org/getting/annualtraffic.aspx. [Accessed: 13-Apr-2017].

[11] Institute of Transportation Engineers., "Trip Generation Manual," 2012. [Online]. Available: http://www.ite.org/tripgeneration/trippubs.asp. [Accessed: 25-Apr-2017].

[12] S. M. Khan, J. Mitchell, M. A. Chowdhury, K. Dey, and N. Huynh, "Operational Analysis of a Connected Vehicle-Supported Access Control on Urban Arterials," *IET Intell. Transp. Syst.*, vol. 12, no. 2, pp. 134–142, 2018.

[13] J. D. Park, B.; Schneeberger, "Microscopic Simulation Model Calibration and Validation: Case Study of VISSIM Simulation Model for a Coordinated Actuated Signal System," *Transp. Res. Rec.*, vol. 1856, pp. 185–192, 2003.

[14] M. A. Siddiqui, "An evaluation of operational effects of corridor-wide access-control modifications | MSU Libraries," Michigan State University, 2011.

[15] P. Liu, D. Ph, X. Qu, H. Yu, W. Wang, and B. Cao, "Development of a VISSIM Simulation Model for U-Turns at Unsignalized Intersections," *J. Transp. Eng. © ASCE*, no. November, pp. 1333–1339, 2012.