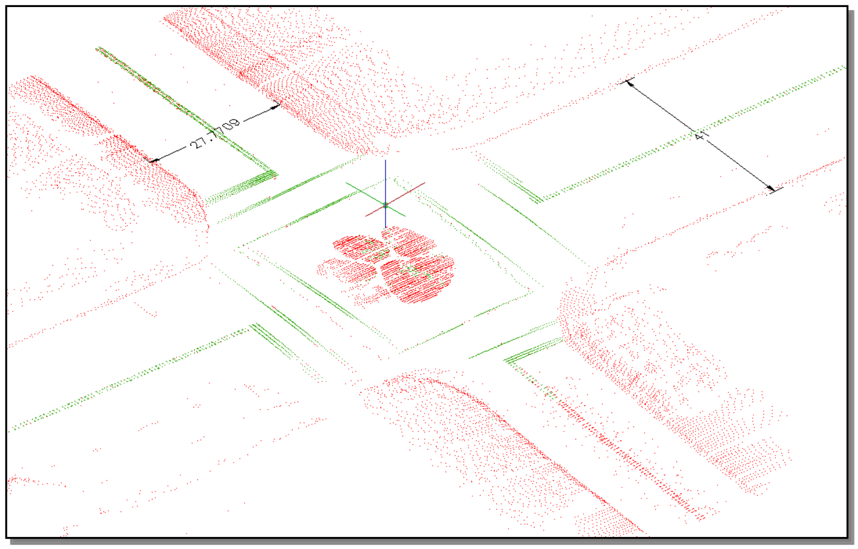
Operational and Safety Characteristics of Lane Widths



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16. Abstract

The primary goal of this study was to investigate and assess the effect of lane widths on the safety and operation of highways in South Carolina. Because of the many site conditions that affect safety and operations on roadways, this type of research is critical to the development of appropriate road design standards. An analysis of crash records, in combination with a geometric inventory of existing highways in South Carolina, allowed for the development of models describing the effect of lane width on crashes. This research also takes into consideration the other confounding variables that affect crash rate, including paved shoulder width, speed limit, and traffic volume. A second phase of the research utilized a driving simulator to assess lane width scenarios that were not available in significant numbers in the field. Findings of this research take the form of design recommendations regarding more flexible selection of applicable lane and shoulder widths for new projects in South Carolina. These recommendations are closely aligned with the 2010 AASHTO Policy on the Geometric Design of Highways and Streets. This research also provides improvement suggestions regarding how crash records are recorded and reported by police officers as well as how geometric roadway characteristics are inventoried and maintained by the South Carolina Department of Transportation (SCDOT). These research findings will prove beneficial as changes are considered for lane width standards in SC.

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Executive Summary

Background and Study Impetus

The 2003 South Carolina Highway Design Guide allows little leeway on suggested lane widths for new projects. There is debate on whether or not using a fixed lane width in different contextual settings is ideal, both from safety and economic standpoints as well as whether it is beneficial to traffic operations. Due to increased project costs and the need to provide context sensitive solutions, the South Carolina Department of Transportation sought to evaluate the SCDOT design standards for travel lane widths and auxiliary lane widths for the purpose of determining the safety and operational effects of adjusting these widths.

For this evaluation, SCDOT issued a problem statement to research the effects of travel lane widths on the safety and operations of non-interstate primary and secondary state routes in South Carolina. It is anticipated that this research will be incorporated in the next edition of the SCDOT Highway Design Manual which will result in long-term economic benefits without compromising the safety and operation of State maintained routes. Because of the many site conditions that affect safety and operations on roadways, this type of research is critical to the development of appropriate road design standards. An analysis of crash records, in combination with a geometric inventory of existing rural highways in South Carolina, allowed for the development of models describing the effect of lane width on crashes. This research also takes into consideration the other confounding variables that affect crash rate, including paved shoulder width, speed limit, and traffic volume. The data-driven research methodology correlated lane widths on a variety of roads of varying characteristics with 3 years of crash data to identify relationships. A follow-on driving simulator study compared and contrasted several design scenarios that were not found in sufficient numbers in the field.

This report summarizes findings of a two-year research project and includes a literature search, discussion of data collection methodology and analysis, and recommended changes to current SCDOT procedures with regard to selection of lane widths for different situations. In most cases the research indicates that the more lenient guidelines set forth in the 2011 AASHTO Policy on the Geometric Design of Highways and Streets should be adopted for use in South Carolina. If implemented, the SCDOT should benefit from a context sensitive methodology to select lane widths. Flexibility helps designers by allowing them to make decisions appropriate to setting and environment. By developing a definitive safety study in South Carolina, this research can help identify how flexibility in design can be utilized.

Introduction

The SCDOT 2003 Highway Design Manual (HDM) specifies a 12 ft. lane width for most new design applications. Many studies across the country have researched existing lane width standards, particularly in regard to the use of narrower lanes in some contextual settings. For example, Potts et al. [2007] researched urban and suburban arterials in Minnesota and Michigan and found little indication that the use of a narrower lane increases crash frequency. They found that changes in lane width tend to have a greater influence on safety for rural roadways than for urban and suburban roadways [Potts et al, 2007]. Therefore, it is important to study lane widths in the contextual settings and environments in South Carolina. As a result, SCDOT has decided to evaluate the 2003 Highway Design Manual standards for lane widths and research how these standards affect the safety and operation of non-interstate, primary and secondary rural routes in South Carolina.

This research focuses on the idea that South Carolina may benefit from implementing more flexible lane width standards on rural and urban highways while prioritizing safety, operations, sustainability, and cost. The results of this research take the form of specific design recommendations regarding the selection of standard lane and shoulder widths for new projects and reconstruction. Ultimately, by using a more flexible approach to the selection of lane widths, the state of South Carolina can continue to grow and develop more sustainable road design projects for the future.

Research Objectives

The overall goal of this project was to investigate and assess the effect of lane width on the safety and operation of highways in South Carolina. Because of the many site conditions that affect safety and operations on roadways, this type of research is critical to the development of appropriate road design standards. The research objectives for meeting the overall research goal include:

1. Review current literature, AASHTO design guidelines, Federal Highway Administration technical material, and other state DOT best practices related to selection of lane width dimensions for various functional roadway classifications.

2. Conduct case study evaluations of selected SC routes to contrast and compare crash history, speed limits, functional classification, contextual setting (urban/suburban/rural), roadside characteristics, clear zone dimensions, and other factors needed to investigate the application of adjusted travel lane width dimension design standards.

3. Conduct a comparative cross-sectional analysis to evaluate the effect of travel lane width dimensions on safety and traffic operations along primary, secondary and other roadway classifications within the SC state highway network.

4. Identify potential impacts of any proposed lane width changes and related cost reductions on safety and traffic operations of the roadway.

5. Conduct analysis to evaluate if current SCDOT standards and guidelines for two-way left turn lane width dimensions are resulting in acceptable levels of safety and traffic operations

6. Develop an effective means to incorporate research recommendations regarding lane width dimensions into appropriate sections and chapters of the SCDOT Highway Design Manual, specifically existing Chapter 9, Basic Design Controls and Chapter 13, Cross Section Elements.

7. Conduct a driving simulator study to test travel lane management treatments including unique lane configurations or redistribution of lane width to shoulder width, as well as the operational effects of smaller two-way left-turn lanes.

Potential Benefits

The results of this research should have significant benefits for SCDOT and users of the state's highways. These benefits fall into several categories. The benefits are related to safety, operations, and potential cost savings to SCDOT. Proposed revisions to the lane widths design criteria specified in the SCDOT Highway Design Manual reflect more flexibility. The revisions will benefit several SCDOT units including Preconstruction, Construction, Traffic Engineering, and Maintenance. The economic benefits will provide support for design decisions that could potentially reduce project impacts, resulting in reduced costs. In addition, a reduction in maintenance costs would be achieved when resurfacing or rehabilitating a route due to the reduced pavement width required. In some cases a reduction in travel lane width may correspond to an increase in shoulder width. Overall, more flexible design standards should lead to more sustainable facilities – especially those roadways with low volumes, low speeds, and limited crash experience.

Research Methods

The main goal of the overall research (Phase A and B) is to determine the influence that flexible lane width standards have on the safety and operation of roadways in South Carolina. Based on the literature review, significant amounts of data were needed to assess the safety and operational impacts associated with lane widths. After reviewing data availability in RIMS and other enterprise systems, the research team embarked on an extensive field data collection effort to obtain lane widths, shoulder widths, side slopes, presence of lighting, etc. Nine counties in South Carolina were ultimately chosen for data collection: Beaufort, Horry, Jasper, Lexington, Orangeburg, Pickens, Richland, Spartanburg, and York. These counties were selected to provide an even mix of Upstate, Midlands, and Coastal conditions. The Clemson Mobile Transportation Lab was used to capture simultaneous laser measurements, GPS, video, etc for over 3000 lane miles of SC highways. The laser data was post processed to determine exact lane widths. Additional data elements were collected from Google Earth and Bing Maps using manual methods. Sites were distributed into bins by function class and geometrics.

The Clemson research team geocoded three years (2007-2009) of crash data for safety analysis. Consistent with the segment selection process, the selection of records was limited to US, State, and Secondary routes only within the selected counties described earlier. In addition, to ensure that crashes less likely to be affected by lane width were excluded, the selection was limited to the following types of crashes:

1. Head-on collisions;
2. Sideswipe events (both opposite direction and same direction); and
3. Run-off-the-road events leading to median crossovers, rollover events, and fixed object collisions.

In the analysis of 5T crashes, angle crashes were added in as well to account for crashes related to the turn lane itself.

The cross-sectional analysis conducted for this research project was intended to serve as the primary tool for comparing roadway safety with lane width. The observational study allowed researchers to investigate the correlation of roadway geometry and related attributes with crash frequency through negative binomial model development similar to that used in the Highway Safety Manual. The model was used to determine how multiple site conditions can affect the safety of a roadway. For each model, two forms of the analysis equation were used. The first version represents the base model and only incorporates segment length and AADT relative to the predicted number of crashes. The second version of each model includes numerous other variables of interest and corresponding regression coefficients. Many of these variables act as categorical variables to define groups of particular site conditions. Thus a base or ideal condition is selected from the available attributes for which all others are compared. Coefficients for each of the variables included in the negative binomial model compare non-ideal conditions to that of ideal. Positive coefficients indicated that roadways within a particular variable group would be expected to have higher crash rates than roadways with ideal conditions for that variable.

Numerous rural and urban highway models were created for the different sample groups with the following ideal conditions:

Rural 2U

- Lane widths of 12 ft
- Paved shoulder widths of 2 ft
- Speed limits of 50 or 55 mph
- Low driveway density (0-25 driveways/mi)
- Level terrain (< 3% grade)

Rural 4D

- Lane widths of 12 ft
- Paved outside shoulders of 2 ft
- Speed limits of 60 or 65 mph

Urban 2U, 3T, 4D, 4U, and 5T

- Lane widths of 12 ft
- Paved shoulder widths of 2 ft
- Speed limits of 50 or 55 mph
- Low driveway density (0-25 driveways/mi)

The field study research also involved the use of a saturation flow rate study to investigate the operational effects of varying lane widths at signalized intersections. Signalized intersection operations are critical for interrupted flow facilities because they represent bottlenecks and are typically located in areas of highest congestion, particularly for urban roadways. Examining the behavior of queues being released from signalized intersections provides a good indication of how traffic will behave at or near saturated conditions. Saturated conditions essentially represent the highest capacity that can be supported before an intersection begins to fail in terms of the level of service and are therefore ideal for the operational analysis.

After the completion of the field studies in Phase A of this study, limited site characteristics made it impractical to study a variety of lane widths through field data collection. Thus, a driving simulator study was developed to enable a controlled comparison of lane, shoulder, and TWLTL widths. Before commencing the study, an extensive literature review was completed to gain knowledge on previous driving simulator studies and to aid in the design of this study. Immense care was taken during the development of the custom design to ensure that sufficient comparative research regarding the SCDOT's inquiries was implemented throughout the study.

The purpose of the Phase B driving simulator study was to supplement the Phase A findings and evaluate the effects of different lane and shoulder width combinations, as well as the effects of different TWLTL widths on driver performance. Lane and shoulder width combinations were examined based on lateral position and out of lane encroachments, while maneuverability and gap acceptance were evaluated for the TWLTLs. The aim of the Phase B was to produce research justifiable minimum design criteria, standards and recommendations for SCDOT engineers and their design consultants regarding which lane, shoulder and TWLTL widths can be applied to roadways to maintain safe and effective operations.

The Phase B simulator study produced additional findings and recommendations with regard to the ultimate goal of using flexible lane width standards in South Carolina. The conclusions will refer back to the study objectives to determine the:

1.) Effect lane and shoulder width combinations have on driver performance.
2.) Effect of curves on lane position for various lane and shoulder width combinations.
3.) Operational performance (gap acceptance and maneuverability) of TWLTLs for minimum and maximum widths.

Research Results

Phase A

Safety effect of lane widths for highway segments

The success of the safety analysis for lane widths was, in many ways, dependent on the variety and consistency of roadway characteristics and the proportion of lane miles available for each of those characteristics in South Carolina. Only significant sample sizes existed for a handful of site types in each of the study counties. The lack of detailed data available in RIMS, and the inconsistency of lane markings in the field only exacerbated the problems of locating suitable samples. After extensive field data collection (over 3000 miles), manual data analysis and database development for 1,292 sites, models were developed for rural two-lane undivided (2U*, 338 sites) and four-lane divided sites (4D*, 37 sites), as well as urban sites including: two-lane undivided (2U*, 75 sites), two-lane with center TWLTL (3T*, 36 sites), four-lane divided (4D, 13 sites) and undivided (4U, 34 sites), and four-lane with center TWLTL (5T*, 257 sites). Models indicated with (*) had significant outcomes. Unfortunately from a modeling perspective, the majority of sites had lane widths of 12 feet – a level of consistency that made comparative modeling difficult. However, the consistency of the 12 foot lane width is a testament to the conformity with the South Carolina design policy that has been in place for a number of years.

In most cases, the resulting models mimicked what has been found nationally with regard to lane widths and safety. Past studies have found that narrower lane widths tend to increase crash rates, particularly on roads with large traffic volumes and high speeds. Almost all of the models developed solely on traffic volume were found to be significant, indicating that increased traffic volume is directly related to increased crash experience. Major findings from rural 2U and 4D, as well as urban 2U, 3T, and 5T are as follows:

Rural two-lane undivided (2U)

The analysis results for the sample of 2U segments indicate only a few significant relationships across the entire set of field variables. As with most road types, models indicated that AADT was significant and positive with respect to crash experience. Narrower lane widths of 10 ft as compared to the ideal value of 12 ft were found to reduce the frequency of crashes within this particular sample. This is contrary to most previous research suggesting that reduced lane width increase crash experience. The anomaly in the analysis results for lane width can most likely be explained by the fact that the sample segments with 10 ft lanes have significantly lower traffic volumes and speed limits than the sample segments with wider lanes. Thus, use of narrower lane widths do not seem to impact safety in low speed, low volume scenarios. Beyond AADT and lane width, the models show no other significant relationships except for the influence of excessive driveways on multi-vehicle crashes.

Additional models were developed for the 2U sample to study the combination of lane and shoulder widths by looking at total pavement width. Thus, widths of 24 ft and 28 ft were compared. The results indicate no significant relationships among lane and shoulder width combinations for a given total pavement width. A study by Gross et al. [2009] found a slight benefit to increasing lane width relative to shoulder width for a fixed total width. The same relationship is carried over into the Highway Safety Manual.

Rural four-lane divided (4D)

Despite starting with a relatively large initial pool of rural 4D road miles, the final 4D dataset is relatively small. During the data collection process, the research team measured both lane widths and sites with greater than a foot difference in the adjacent lanes were removed from the sample. The large majority of sites were removed due to this lane imbalance. In a meeting with the steering committee, the imbalance seems to stem from the placement of temporary lane markings during construction or resurfacing.

The segments selected for the rural 4D sample have predominantly grassy medians. Very few samples had bituminous medians, so models could not be developed. The analysis results for the sample of rural 4D grassy median segments do not indicate any significant relationships across the entire set of field variables with the exception of AADT. For rural four-lane divided segments there was little variability in lane width within the sample and only a small number of 11 ft segments. Thus, a model could only be developed to compare segments with 11 or 12 ft lanes. The HSM Crash Modification Factors for lane width on rural multilane highways show little difference between the use of 11 and 12 ft lanes, even on roads with a high AADT (HSM, 2010).

Beyond lane width, the model indicated a tendency for reduced crashes on segments with lower speeds, although the relationship was not significant. Regarding shoulder width, few segments were collected with shoulder widths above 2 ft. As a result, an analysis could only be developed to compare no shoulder with 2 ft shoulders, and results show no significant influence.

Urban two-lane undivided (2U)

Neither the base model nor full-variable model for Urban 2U roadway segments showed a significant correlation between AADT and predicted number of total crashes. For driveway density, a significant positive correlation indicates that crash frequency is higher for roadway segments with medium driveway density than for low driveway density. The insignificant results for high driveway density are likely caused by the low number of segments that fell into that category.

Urban two-lane with center TWLTL (3T)

Due to the lack of available sample sizes for multiple lane widths categories in the 3T model, a different approach was required. To generate some measure of lane width's relationship with crash frequency, a separate model is used with a subset of the original sample to compare the segments that meet or exceed the "ideal" total pavement width with those that do not. For this model, AADT is positively and significantly correlated to crash frequency. While no significant correlation is found for the total pavement width with, it is worth noting that the coefficient for less than ideal total pavement width is positive, indicating a potential increase in crash frequency with lesser roadway widths**.** No significant results were identified with respect to TWLTL widths.

Urban four-lane with center TWLTL (5T)

For the urban 5T models, AADT is found to have a significant positive correlation with crash frequency. The 35 mph and under speed limit also has a statistically significant positive coefficient. The general trend for speed limit suggests that total crashes increase as speed limit decreases – this may reflect less access management on lower speed facilities. Only high driveway density has a significant positive coefficient value compared to low driveway density. The trends observed for roadside features show that the presence of curb and gutter only and the absence of curb and gutter/shoulders have significant positive coefficients with the latter having the highest one. This is in comparison to roadway segments with shoulder and curb/gutter which have significantly lower crashes.

Operational effect of lane widths at signalized intersections

Ultimately, the field study of saturation flow rate at signalized intersections resulted in no significant lane width relationships within the constraints of this study. Measurements were taken at 501 sites including 238 through lanes, 86 un-skewed left turn lanes, 63 skewed left turn lanes, and 114 shared left/through lanes. These findings are consistent with the Highway Capacity Manual which does not recommend the use of saturation flow rate adjustments for lane widths from 10 ft to 12.9 ft [TRB, 2010]. Lane widths below 10 ft. were observed in very limited numbers; and therefore, did not generate significant results.

Phase B

Effect of lane and shoulder width combinations on driver performance

Driver performance was measured by assessing the percent time out of lane and number of out of lane encroachments. These measurements were evaluated for three lane and shoulder width combinations (a 12 ft. lane width and no shoulder, a 12 ft. lane width with a 2 ft. paved shoulder, and a 10 ft. roadway with a 2 ft. paved shoulder). There was very little difference between the two 12 ft. roadway combinations. A total of 5 participants went out of the lane for the 12 ft. roadway with no shoulder and 7 participants drove out of the lane for the 12 ft. roadway with a 2 ft. shoulder. One important consideration is that lane encroachments with no shoulder can be more severe in the real world – especially if there is a significant pavement edge drop off. However, for the 12 ft. lane width and no shoulder, only one encroachment was to the outside edge, therefore only this one exceeded the boundaries of the paved surface.

A larger difference was seen between the two 12 ft. lane combinations when the total number of encroachments was calculated. The 12 ft. roadway with no shoulder had 6 encroachments while the 12 ft. roadway with a 2 ft. paved shoulder had 13 encroachments. The increase in encroachment numbers with the added shoulder is likely a function of the additional space. In previous studies it has been found that providing extra paved space evokes a sense of security and safety as there is more room for error and corrections. It is noteworthy that none of the shoulder encroachments went beyond the paved portion of the shoulder.

Results from the 10 ft. lane combination show increased effects. The limited lane width scenario had a total of 14 participants drive out of the lane boundary with 28 encroachments. None of the encroachments left the paved surface. Due to the reduction in lane width it was expected that the drivers would have the most difficulty with this combination. There was also a difference in the general lane position for the 10 ft. lane width. The average lane position values for both of the 12 ft. lane width scenarios were to the left of the roadway centerline (-.212 ft. for the 12 ft. roadway with no shoulder, -.100 ft. for the 12 ft. roadway with a 2 ft. shoulder). Only the 10 ft. lane width had an average lane position toward the outside edge of the road at 0.149 ft. from the centerline.

One interesting finding of the Phase B study with regard to encroachments is that most of the encroachments that occurred happened on curve sections. Only 2 drivers (out of 60) encroached on straight sections and these encroachments only went into the 2 foot shoulder. Overall, the drivers only experienced one encroachment which left the paved portion of the roadway/shoulder. While the 10 ft. lane width did have increased encroachments, these were all within the bounds of the 2' paved shoulder. These results also support the Highway Safety Manual analysis conducted in Phase A, showing that there is only a 0.2 total crash per mile difference between the three combinations tested in the driving simulator.

Effect of curve radii on lane keeping and encroachments

The numbers of encroachments were also evaluated based on the curve radii. All of the curve radii in the three scenarios were split into three categories of small, medium and large. The small curves fell in the range of 900- 1230 ft. Curves within the range of 1231-1500 ft. were recognized as medium and large curves were between 1501-5500 ft. Based on these ranges and the radii of the curves given in the scenarios, almost 45% of encroachments were experienced on the small radii curves, and over 75% were on small and medium curves. Curves to the left were also more involved in encroachments than curves to the right. To combat the effect of curves, curve widening and increased clear zones in curve sections (particularly on curves to the left) can be used to mitigate issues associated with the use of narrower lanes.

Operational performance (gap acceptance and maneuverability) of TWLTLs widths

For the TWLTL driver simulator study, gap data was collected for two 3T and 5T left turns. TWLTL widths of 12, 14 and 16 ft. were tested for 3T and 5T sections. Based on the average gap, many comparisons were made to determine if the TWLTL width had any effect upon gap acceptance. First, the average gaps for all turns in the 3T sections per scenario were compared between each other. Results from the analysis found no significant gap difference between any of the scenarios, thus indicating that there was no effect on gap acceptance due to the TWLTL width. Another comparison was made by separating the gap data by the order in which the scenarios were driven. To be specific, this grouped gap data by participant's first, second and third scenario driven. These averages were 5.88 seconds for the first scenario, 5.08 seconds for the second scenario and 4.90 seconds for the last. Analyses indicated a significant difference between the first and second scenario and the first and last scenario, but not between the second and third scenarios. This indicates that the participants drove more cautiously for the first scenario as they were unaccustomed to the scenario layout and the left turn maneuver into the center lane. As each scenario had two turns, additional comparisons were made to determine if there was a difference between the first and second turn. These differences were statistically significant as the majority of the participants accepted smaller gaps for the second turn than the first. This further indicates that the first turn was used as a learning opportunity.

The 5T turns were also analyzed separately. The average gaps were 4.5 seconds for the 12 ft. TWLTL, 4.8 seconds for the 14 ft. TWLTL, and 4.6 seconds for the 16 ft. TWLTL. Similar to the 3T results the comparison analysis for the 5T sections revealed no significant difference between scenarios. Overall, the TWLTL width had no effect upon gap acceptance. The only effect found was due to the order, first second and third, in which participants drove the scenarios.

Additional analyses were performed to test how the TWLTL width affected participants' ability to maneuver into and within the TWLTL when they performed their left turn. For this portion of the analysis, vehicle trajectories were drawn for 30 participants' second 3T turn in each scenario. The variation in lane position and maneuverability clearly increased as the TWLTL lane width increased. The participants were more cautious and controlled when turning into the smaller 12 ft. TWLTL width. As the TWLTL width increased the participants tended to utilize more of the TWLTL width as they made their left turn. Few indications of encroachments to the travel lanes were detected, and those that were detected were corrected by the driver in most cases.

Age comparisons

Driver characteristics pertaining to age were also tested in relationship to gap acceptance. Results found that for each scenario the average gap accepted for older participants was higher than the average gap accepted by younger participants. The overall averages of 4.82 s for young and 5.23 s for the older participants were found to be statistically significant. Similar to the Yan et al. study, these results found that older drivers drive more conservatively.

Highway Design Manual Recommendations

The literature review and results from this research provide evidence for the application of flexible lane width standards for South Carolina highways. Based on findings from the Phase A field study and Phase B driver simulator research, numerous changes are identified for the SCDOT Highway Design Manual (HDM). Recommendations are primarily focused on Chapter 20, Rural Highways, and Chapter 21, Suburban/Urban Streets, however other HDM chapters that are referenced to criteria provided in these chapters would also need to be changed or modified. Proposed changes and modifications, from Phase A and B research findings, are summarized in the following tables. The criteria and conditions column indicates whether the criteria are recommended per AASHTO policy or if there are modifications based on research results.

It should be noted that travelway widening on horizontal curves was verified to be an important roadway design element as for all scenarios tested results from the driver simulator provided evidence of considerably more encroachments along curved roadway sections. SCDOT HDM Figure 11.2F provides values for travelway widening. The importance of adhering to these threshold criteria was evident in results from the driver simulator research for passenger vehicles, and not just truck design vehicles.

Table E.1 Recommendations for Proposed Width Criteria for Rural Two-Lane Arterials

<table>
<tr><th>Variable</th><th>Values</th><th>Criteria and Conditions</th></tr>
<tr><td>Travelway Width</td><td>20*-24 ft.</td><td>(AASHTO Criteria = 22-24 ft.)
*20 ft. travelway width must include an additional 2ft paved shoulder and be used only in low speed environments where crash history permits</td></tr>
<tr><td rowspan="4">Travel Lane Width (*)</td><td>11 ft. min., 12 ft. desirable</td><td>AASHTO Criteria
Design Speed 55 mph or less, assuming a 2 ft. paved shoulder, if shoulder width does not meet minimum requirements, use 12 ft. min</td></tr>
<tr><td>12 ft. min.</td><td>AASHTO Criteria
Design Speed 60 mph or greater, 2 ft. paved shoulder is desirable or satisfactory roadside maintenance</td></tr>
<tr><td>10 ft.</td><td>Clemson Research Indicates that 10 ft. lane width would be allowable for design speed of 40 mph or less in conjunction with 2 ft. minimum paved shoulder width. (Note, this is below the range published by AASHTO)</td></tr>
<tr><td colspan="2">* Footnotes:
1. If lower design speeds are allowed, narrower travel lane widths could be acceptable, 10 ft. min.
2. For industrial areas or locations with higher heavy vehicle use, 12 ft. lanes should be used.
3. Criteria for Travel Lane Width assumes no problematic prior crash histories related to lane width including run off the road, sideswipe (same and opposite direction), head-on crashes.
4. Under no condition should travel lane widths be less than 10 ft. min.
5. As identified in SC HDM Figure 11.2F, criteria for travelway widening on horizontal curves should be accommodated for 12 ft., 11 ft. and 10 ft. travel lanes.</td></tr>
<tr><td>Auxiliary Lane Width</td><td>11-12 ft.</td><td>AASHTO Criteria</td></tr>
<tr><td>TWLTL Width</td><td>11-16 ft.</td><td>AASHTO Criteria
No simulator observed effect on gap acceptance or driver behavior for 12 ft. and up, 11 ft. was not tested</td></tr>
</table>

Table E.2 Recommendations for Proposed Width Criteria for Rural Two-Lane Collectors

Variable	Values	Criteria and Conditions
Travelway Width	20-24 ft.	AASHTO Criteria
Travel Lane Width (*)	10 ft. min.	AASHTO Criteria AADT less than 400 veh/day, design speed 40mph or less, Min. 2 ft. paved shoulders should be provided for all roadway applications
	11 ft. min.	AASHTO Criteria AADT between 401-2000 veh/day, design speed 50mph or less, assuming a 2 ft. paved shoulder, if shoulder width does not meet minimum requirements, use 12 ft. min
	12 ft. min.	AASHTO Criteria AADT over 2,000, design speed 60 mph or greater; 2 ft. paved shoulders desirable or satisfactory roadside maintenance
	*Footnotes: 1. If lower design speeds are allowed, narrower travel lane widths could be acceptable, 10 ft. minimum 2. For industrial areas or locations with higher heavy vehicle use, 12 ft. lanes should be used. 3. Criteria for Travel Lane Width assumes no problematic prior crash histories related to lane width including run off the road, sideswipe (same and opposite direction), head-on crashes. 4. Under no condition should travel lane widths be less than 10 ft. minimum 5. As identified in SC HDM Figure 11.2F, criteria for travelway widening on horizontal curves should be accommodated for 12 ft., 11 ft. and 10 ft. travel lanes.	
Auxiliary Lane Width	11-12 ft.	AASHTO Criteria
TWLTL Width	11-16 ft.	AASHTO Criteria No simulator observed effect on gap acceptance or driver behavior for 12 ft. and up, 11 ft. was not tested

Table E.3 Recommendations for Proposed Width Criteria for Rural Four-Lane Divided Arterials

Variable	Values	Criteria and Conditions
Travelway Width	22-24 ft.	AASHTO Criteria
Travel Lane Width (*)	11-12 ft.	AASHTO Criteria
Auxiliary Lane Width	11-12 ft.	AASHTO Criteria

Table E.4 Recommendations for Proposed Width Criteria for Urban/Suburban Arterials and Collectors

Road Type	Variable	Values	Criteria or Conditions
Four-Lane Urban Street	Traveled Way Width	22-24 ft.	AASHTO Criteria
Five-Lane Urban Street (with Shoulders or Curb and Gutter)	Travel Lane Width	11-12 ft.	AASHTO Criteria
	TWLTL Lane Width	11-16 ft.	AASHTO Criteria
Suburban/Urban Multilane Arterials	Travel Lane Width	11-12 ft.	AASHTO Criteria
	TWLTL Lane Width	11-16 ft.	AASHTO Criteria No simulator observed effect on gap acceptance or driver behavior for 12 ft. and up, 11 ft. was not tested
Suburban/Urban Collectors	Travel Lane Width	22-24 ft.	AASHTO Criteria
	TWLTL Lane Width	11-16 ft.	AASHTO Criteria No simulator observed effect on gap acceptance or driver behavior for 12 ft. and up, 11 ft. was not tested

In addition to specific changes to the SCDOT HDM, shown in the accompanying tables, more generalized changes and modifications are also recommended. From the survey of states and review of national literature, other State DOT's are using innovative approaches to supplement primary criteria and to provide additional flexibility with regard to lane width guidelines. Proposed changes and modifications to the SCDOT HDM include the following additional approaches.

Identify and provide design criteria for special area designations that are in addition to commonly used rural and suburban/urban arterial and collector roadway design criteria and address numerous guidelines for lane widths, access management, parking, pedestrians, bike lanes and traffic calming. Oregon DOT uses this approach and special designations include: Special Transportation Areas (STAS), Urban Business Areas (UBAs), and Commercial Centers (CCs). These special designations are briefly summarized as follows: 1.) STA characteristics and attributes include: well-developed parallel and interconnected local roadway network, adjacent land uses that provide for compact, mixed use development, on street parking, and well-developed transit, bicycle and pedestrian facilities and design speeds from 25-30 mph, 2.) UBA characteristics and attributes include: intersections designed to address the needs of pedestrians and bicyclists, provision of transit stops, inter-parcel circulation, and design speeds generally 35 mph or greater, and 3.) CC characteristics and attributes include: Shared parking and a reduction in parking to accommodate multimodal elements where alternate modes are available, compact development patterns, accessibility by a variety of routes and modes, and integration with the local road network. These proposed changes could be included in SC HDM, Chapter 9, Basic Design Controls, and new geometric design criteria tables for special area designations would be required for Chapter 20, Design of Rural Highways and Chapter 21, Design of Suburban and Urban Streets.

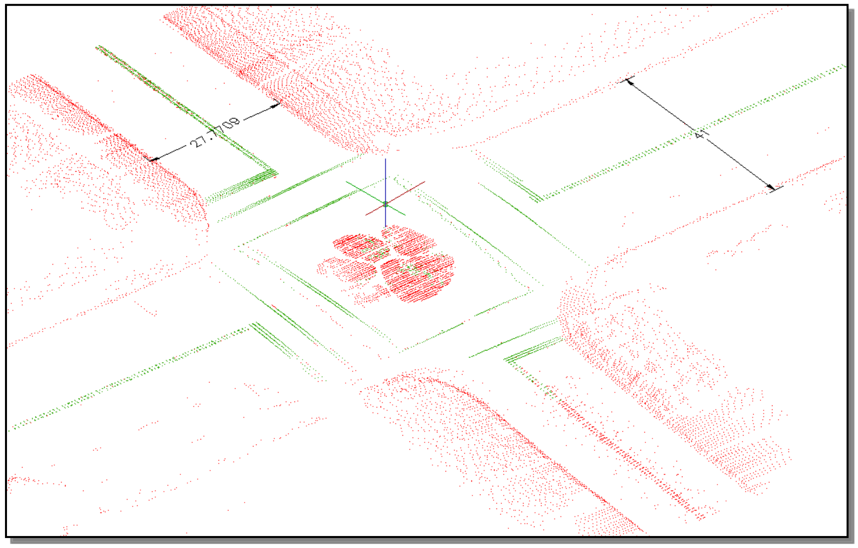
Include new sections or commentary regarding complete streets, context sensitive design, road diets, traffic calming and/or project right sizing. Many state DOT's have modified their highway design procedures to include these types of guidelines that result in increased flexibility in guidelines for special areas and special project objectives. These proposed changes could be included in a number of locations of the SCDOT HDM, and a likely location to introduce links to relevant locations would be Chapter 9, Basic Design Controls.

Lastly, SCDOT HCM, Chapter 9, Basic Design Controls, could be modified to include requirements for multimodal Level of Service (LOS) analysis, when relevant. Multimodal level of service analysis, as developed in the 2010 Highway Capacity Manual, includes combined operational analysis procedures for motor vehicles, transit, bicycles, and pedestrians for the purpose of determining an overall operation of a roadway environment across multiple travel modes. This could be used as an effective approach for triggering additional flexibility for lane width criteria in evaluating highway designs for suburban and urban areas.

Report Organization

This remainder of this report is organized into two phases. Phase A details the field study of operational and safety effects of lane widths, and Phase B details the simulator study which followed up on issues where insignificant sample sizes precluded development of recommendations for the South Carolina Highway Design Manual. Both phase reports include an introductory chapter, a literature review chapter, as well as methods, results, and conclusions/recommendations chapters. Appendices are also provided to support and expand upon the methods and findings of respective phases. Each phase can be identified by the page numbers. Phase A page numbers are indicated with 'A-' and phase B are indicated with 'B-'.

Operational and Safety Characteristics of Lane Widths



PHASE A

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1.0 INTRODUCTION

1.1Introduction and Problem Statement

The 2003 South Carolina *Highway Design Manual* (HDM) allows little flexibility regarding recommended lane widths for new roadway projects [South Carolina Highway Design Manual, 2003]. Many studies across the country have researched existing lane width standards, particularly in regard to the use of narrower lanes in some contextual settings. For example, Potts et al. [2007] researched urban and suburban arterials in Minnesota and Michigan and found little indication that the use of a narrower lane increases crash frequency. They found that changes in lane width tend to have a greater influence on safety for rural roadways than for urban and suburban roadways [Potts et al, 2007]. Therefore, it is important to study lane widths in the contextual settings and environments in South Carolina. As a result, SCDOT has decided to evaluate 2003 design standards for lane widths and research how these standards affect the safety and operation of non-interstate, primary and secondary rural routes in South Carolina.

This research focuses on the idea that South Carolina may benefit from implementing more informed/adaptable lane width standards on highways while prioritizing safety, operations, sustainability, and cost. The results of this research take the form of specific design recommendations regarding the selection of standard lane and shoulder widths for new projects and reconstruction. Ultimately, by using a more flexible approach to the selection of lane widths, the state of South Carolina can continue to grow and develop more sustainable road design projects for the future.

1.2 Research Objectives

The overall goal of this project was to investigate and assess the effect of lane width on the safety and operation of highways in South Carolina. Because of the many site conditions that affect safety and operations on roadways, this type of research is critical to the development of appropriate road design standards. The research objectives for meeting the overall research goal include:

1. Review current literature, AASHTO design guidelines, Federal Highway Administration technical material, and other state DOT best practices related to selection of lane width dimensions for various functional roadway classifications.

2. Conduct case study evaluations of selected SC routes to contrast and compare crash history, speed limits, functional classification, contextual setting (urban/suburban/rural), roadside characteristics, clear zone dimensions, and other factors needed to investigate the application of adjusted travel lane width dimension design standards.

3. Conduct a comparative cross-sectional analysis to evaluate the effect of travel lane width dimensions on safety and traffic operations along primary, secondary and other roadway classifications within the SC state highway network.

4. Conduct analysis to evaluate if current SCDOT standards and guidelines for two-way left turn lane width dimensions are resulting in acceptable levels of safety and traffic operations

5. Identify potential impacts of any proposed lane width changes and related cost reductions on safety and traffic operations of the roadway.

6. Develop an effective means to incorporate research recommendations regarding lane width dimensions into respective chapters of the SCDOT Highway Design Manual.

7. Conduct a driving simulator study to test travel lane management treatments including unique lane configurations or redistribution of lane width to shoulder width, as well as the operational effects of narrower two-way left-turn lanes. (Conducted in Phase B)

1.3 Benefits

The results of this research should have significant benefits for SCDOT and users of the state's highways. These benefits fall into several categories. The benefits are related to safety, operations, and potential cost savings to SCDOT. Proposed revisions to the lane widths design criteria specified in the SCDOT Highway Design Manual will reflect more flexibility. The revisions will benefit several SCDOT units including Preconstruction, Construction, Traffic Engineering, and Maintenance. The economic benefits will provide support for design decisions that could potentially reduce project impacts, resulting in reduced costs. In addition, a reduction in maintenance costs would be achieved when resurfacing or rehabilitating a route due to the reduced pavement width required. In some cases a reduction in travel lane width may correspond to an increase in shoulder width. Because the design requirements for travel lanes can exceed requirements for shoulder widths, a cost savings may be experienced. Overall, more flexible design standards should lead to more sustainable facilities – especially those with low volume roadways with limited crash experience.

1.4 Report Organization

This report is organized into five chapters. Chapter 2 provides a review of relevant literature and the results of a survey of state highway design guides. Following the literature review, Chapter 3 provides a detailed description of the methods used to conduct this study, including relevant data sources and considerations throughout the process. The results of this research are presented in Chapter 4. Numerous findings are provided regarding the cross-sectional analysis process, and this is used to make recommendations regarding the selection of lane widths in South Carolina. Finally, Chapter 5 includes some final conclusions regarding the success of this project and recommendations for selecting lane and shoulder widths on various types of highways. Appendices are also provided to support and expand upon the findings of this project.

2.0 LITERATURE REVIEW AND SURVEY OF STATES

2.1 Literature Review

Members of the research team entered the project having some knowledge of relevant literature discussing safety and geometric design. This knowledge was expanded upon and enhanced at the onset of the project by performing a complete literature review of contemporary issues in this area. With the use of online library databases such as Transport Research International Documentation (TRID), relevant AASHTO documentation, project reports from programs including the National Cooperative Highway Research Program (NCHRP), and relevant conference proceedings, a framework was created for the research approach moving forward. The team also reviewed the current South Carolina Highway Design Manual, AASHTO Policy on Geometric Design of Highways and Streets, and the Highway Safety Manual to gain a better understanding of the current requirements and standards used in South Carolina and how they compare to national standards and safety analysis.

Past research on the safety and operational effects of lane widths on rural highways indicates that flexibility in selecting lane widths on new projects in South Carolina is appropriate in some scenarios. Because of the many site location conditions that affect safety and operations on roadways, this type of research is critical to the development of appropriate design policies. Studies on lane width and operations date back to 1944, when Taragin identified 12 ft lanes as optimal on two-lane concrete roads. Taragin [1944] found that lanes narrower than 11 ft were hazardous for moderate traffic volumes, but 12 ft lanes were most appropriate and were required to provide clearances for commercial traffic.

Today, designers face new difficulties in identifying acceptable lane widths for varying contextual settings. In many cases, the use of wider lanes in design tends to increase project costs and sometimes travel speeds. Additionally, wider lanes can leave less space for the surrounding environment and the communities through which roadways are being built. However, this consideration for the use of narrower lanes must be balanced with the effect of potential design changes on the safety and operation of the roadway. In a prior study, Potts et al. [2007] researched urban and suburban arterials in Minnesota and Michigan and found no indication, except in limited cases, that the use of narrower lane increases crash frequency [Potts et al., 2007]. In general, changes in lane width tend to have a greater influence on safety among rural highways, but it is important to apply some of these lane width studies to the contextual settings and environments in South Carolina, as changes in socio-demographics, topography, and other factors can significantly affect the driving environment and outcomes.

Thus, the ultimate goal in analyzing past lane width research is to determine significant relationships among design and traffic factors, review methods for assessing safety and operational effects of lane widths, and successfully apply these finding within the contextual settings of this project. By determining the effect of using narrower lane widths on safety in South Carolina, recommendations will be provided regarding the potential for flexible design on rural and urban highways.

2.1.1 Current Geometric Design Policies for Lane Width

The American Association of State Highway and Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets*, otherwise known as the "Green Book," provides standards for the selection of lane widths on various functional classifications of roadways, including both rural and urban highways as well as collector and arterial roadways. Although AASHTO identifies a 10-12 ft range from which lane widths can typically be selected for specific circumstances, some State DOTs have policies in place that restrict the selection of lane widths less than 12 ft [Kueper, 2010]. The "Green

Book” allows lane widths under 12 ft in the following circumstances [AASHTO 2011]:

1. 11 ft where pedestrian crossings are prevalent or in areas with restrictions caused by right-of-way for existing developments;
2. 10 ft on low-speed (< 30 mph) facilities;
3. 9 ft on low-volume (< 250 AADT) roads in rural and residential areas.

Tables 2.1 and 2.2 below provide a comparison between the design standards for new rural roadways in the 2011 AASHTO *Policy on Geometric Design of Highways and Streets* and the 2003 South Carolina *Highway Design Manual* . Tables 2.3 and 2.4 provide existing AASHTO design tables from Chapters 6 and 7 of the “Green Book” for traveled way and usable shoulder on rural highways [AASHTO, 2011]. The usable shoulder standards outlined in these tables are applied to urban roadways as well. The design standards below make consideration for lane width, shoulder width, TWLTL width, and median width on both urban arterials and collectors. The 2001 AASHTO “Green Book” standards [AASHTO, 2001], from which the existing South Carolina standards were developed, are identical to the 2011 AASHTO standards for the design of lane and shoulder widths [AASHTO, 2011].

Table 2.1: Existing South Carolina Design Standards by Functional Class [SCDOT, 2003]

Functional Class	**Variable**	**2003 SC HDM**	
		Standard Minimum (ft)	**Conditions**
Rural Two-Lane Arterial	Lane Width	12	-11 ft permitted for reconstruction
	Shoulder Width	10 (2 paved)	-
Rural Two-Lane Collector	Lane Width	11-12	-12 ft for AADT > 2000 -11 ft for AADT < 2000, also for reconstruction -10 ft may only be considered for AADT < 250 and design speeds ≤ 40 mph
	Shoulder Width	6-8 (No paved)	-
Rural Four-Lane Arterial	Lane Width	12	-11 ft permitted for reconstruction
	Shoulder Width	10 (2 paved)	-
Urban/Suburban Arterial	Lane Width	12	-
	Shoulder Width	10 (2 paved) OR Curb+Gutter	-
	TWLTL Width	15	-
	Depressed Med. Width	36	-
	Flush Med. Width	4-12	-
Urban/Suburban Collector	Lane Width	12	-
	Shoulder Width	8 (2 paved) OR Curb+Gutter	-
	TWLTL Width	15	-
	Flush Med. Width	4-12	-

Table 2.2: Existing AASHTO Design Standards by Functional Class [AASHTO, 2011]

Functional Class	**Variable**	**2011 AASHTO "Green Book"**	
		Standard Minimum (ft)	**Conditions**
Rural Two-Lane Arterial	Lane Width	11-12, See Table 2.3	-11 ft permitted for reconstruction
	Shoulder Width	4-8 (2 Paved), See Table 2.3	-Preferably, usable shoulders are paved. -2 ft paved shoulders allowed for reducing construction impacts as long as bicycle use not intended
Rural Two-Lane Collector	Lane Width	10-12, See Table 2.4	-11 ft permitted for reconstruction -9 ft for AADT < 250
	Shoulder Width	2-8 (Not Paved), See Table 2.4	-May be reduced for design speeds > 30 mph if roadway width > 30 ft
Rural Four-Lane Arterial	Lane Width	12	-11 ft permitted for reconstruction
	Shoulder Width	8 (Not Paved)	-Paved portion is preferred
Urban/Suburban Arterial	Lane Width	10-12	12 ft desirable on high-speed, free-flowing arterials 11 ft acceptable and common 10 ft may be used for design speeds < 35 mph, as long as little truck or bus traffic exists
	Shoulder Width	See Conditions	If provided, shoulders should be in accordance with Table 2.3 Otherwise, use Curb+Gutter
	TWLTL Width	10-16	-
	Depressed Med. Width	-	-
	Flush Med. Width	-	-
Urban/Suburban Collector	Lane Width	10-12	Exceptions: 12 ft for industrial areas, except with lack of space Where shoulders are provided, see Table 2.4 for lanes
	Shoulder Width	See Conditions	Where provided, roadway widths should be in accordance with Table 2.4
	TWLTL Width	10-16	-
	Flush Med. Width	2-4 OR 10-16	-

Table 2.3: AASHTO Width Standards for Rural Arterials [AASHTO, 2011]

Design Speed (mph)	Minimum Width of Traveled Way (ft) for Specified Design Volume (veh/day)			
	under 400	400 to 1500	1500 to 2000	over 2000
40	22	22	22	24
45	22	22	22	24
50	22	22	24	24
55	22	22	24	24
60	24	24	24	24
65	24	24	24	24
70	24	24	24	24
75	24	24	24	24
Width of Shoulder (Non-paved) on Each Side of Road (ft)				
All Speeds	4	6	6	8

Table 2.4: AASHTO Width Standards for Rural Collectors [AASHTO, 2011]

Design Speed (mph)	Minimum Width of Traveled Way (ft) for Specified Design Volume (veh/day)			
	under 400	400 to 1500	1500 to 2000	over 2000
20	20	20	22	24
25	20	20	22	24
30	20	20	22	24
35	20	22	22	24
40	20	22	22	24
45	20	22	22	24
50	20	22	22	24
55	22	22	24	24
60	22	22	24	24
65	22	22	24	24
Width of Shoulder (Non-paved) on Each Side of Road (ft)				
All Speeds	2	5 (> 30 mph)	6	8

The AASHTO and state design standards for lane width clearly define different standards for the design of lane and shoulder widths, and two-way left-turn lanes (TWLTLs). Chapter 20 of the 2003 South Carolina HDM allows for the retaining of existing 11 ft lanes on all reconstructed rural arterials based on an engineering study, but otherwise, designers are kept to the standard of 12 ft. On rural two-lane collectors, there is some allowance for the use of 11 ft on new projects with an average annual daily traffic (AADT) volume below 2,000 veh/day. In addition, where the design speed is 40 mph or lower and the AADT is below 250 veh/day, 10 ft travel lanes may even be used [South Carolina Highway Design Manual, 2003]. Chapter 21 of the 2003 South Carolina HDM only allows the use of 12 ft lanes and 15 ft TWLTLs for all new urban roadway design projects. However, one of the main points of emphasis in determining how lane widths can be more flexibly used is to consider those roadways with significant traffic volumes. In determining to what extent lane width affects safety in South Carolina, this research will provide recommendations regarding the potential for more flexible geometric design. [SCDOT, 2003]

Context-sensitive design is one way of describing the movement for more flexibility in geometric design. Transportation facilities that are context-sensitive tend to preserve the surrounding natural environment through both land and community preservation. The situational use of narrower lanes can be quite beneficial for a variety of reasons, including:

1. Lower construction costs;
2. Additional space for auxiliary lanes and the placement of roadside hardware;
3. Context-sensitive benefits such as the preservation of surrounding neighborhoods and streets, shorter pedestrian crossing distances, and additional space for bicycle lanes, wider sidewalks, or even buffer areas between pedestrians and vehicles [Potts et al, 2007].

Using narrower lanes is quite applicable to the movement toward context-sensitive solutions by providing more efficient transportation and more sustainable and livable streets in general. One of the major issues related to designing with narrower lanes is the willingness of designers to adopt context-sensitive solutions throughout the design process. Through a better understanding of the safety effects of varying lane widths in South Carolina, this research will provide clear, context-sensitive standards for all designers.

2.1.2 Safety Effects of Lane Width by Road Type

There are several types of crashes that tend to be heavily influenced by lane width, including single vehicle run-off-the-road, multiple-vehicle head-on, as well as same- and opposite-direction sideswipe crashes [AASHTO, 2010]. By limiting the selection of crashes for analysis to these types, a more conclusive relationship between lane width and safety can be developed.

This research project categorized segments in accordance with the classification of roadways in the *Highway Safety Manual*. The following types of facilities were considered for analyzing the safety effects of narrowing lane widths [AASHTO, 2010]:

1. Rural
   a. Two-Lane, Two-Way Roads – Undivided roadway segment (2U)
   b. Multilane Highways – Undivided four-lane roadway segment (4U), Divided four-lane roadway segment (4D)
2. Urban
   a. Two-lane, Two-Way Roads – Undivided roadway segment (2U), Three-lane roadway with TWLTL (3T)
   b. Multilane Highways – Undivided four-lane roadway segment (4U), Divided four-lane roadway segment (4D), Five-lane roadway segment with TWLTL (5T)

2.1.2.1 Rural Two-Lane Highways

Rural two-lane highways are only categorized into undivided roadway segments (2U) within Chapter 10 of the HSM [AASHTO, 2010]. This encompasses all rural two-lane roadways with a continuous cross section, two-directions of travel, and lanes that are not separated by physical distance or barrier. In addition, the HSM definition includes any three-lane sections that contain a two-way left-turn lane (TWLTL) in the center as well as any sections containing additional passing lanes in one or both directions. Two-lane divided roadway segments (2D) are not modeled separately from undivided roadway segments because a representative sample size has not been identified for 2D segment analysis yet. The HSM uses the following characteristics to analyze and predict crash frequency on two-lane, two-way roads [AASHTO, 2010]:

1. Segment Length (mi)
2. AADT volume (vehicles per day)
3. Lane width
4. Shoulder width
5. Shoulder type
6. Driveway density (driveways per mile)
7. Grade (percent)
8. Roadside hazard rating
9. Presence/absence of centerline rumble strip
10. Presence/absence of lighting
11. Presence/absence of automated speed enforcement

For rural two-lane highways, crash rate tends to increase as lane width decreases. The same is true for the width of paved shoulders on rural two-lane highways. These relationships are generally accepted for these types of roads. Harwood et al. [Harwood et al, 2000] studied rural, two-lane, two-way roads and confirmed this relationship for lane widths. The study tested the effect of lane width alone against a baseline of 12 ft lanes, 6 ft paved shoulders, level grade, five driveways per mile, a roadway hazard rating of 3, and no passing lanes or short four-lane sections. Results indicate that safety is not particularly sensitive to lane width under low-volume conditions, but at higher volumes, the sensitivity is larger. Table 2.5 displays these results below.

Table 2.5: Sensitivity of Safety to Lane Width on Rural Two-Lane Highways [Harwood et al, 2000]

	Lane Width (ft)			
ADT (veh/day)	9	10	11	12 (Base)
	Accidents per Mile per Year			
400	0.09	0.09	0.09	0.09
1000	0.24	0.23	0.23	0.22
3000	0.79	0.74	0.68	0.67
5000	1.32	1.24	1.14	1.12
10000	2.64	2.48	2.28	2.24
	Accidents per Million Vehicle-Miles			
400	0.63	0.62	0.62	0.61
1000	0.66	0.64	0.62	0.61
3000	0.72	0.68	0.63	0.61
5000	0.72	0.68	0.63	0.61
10000	0.72	0.68	0.63	0.61

The HSM provides Crash Modification Factors (CMFs), which act as a quantified way of describing the effects of treatments, geometric changes, or operational changes on crash rates on a particular road. The research that developed the basis for the HSM included a comprehensive screening process. As a result, the CMFs verified for inclusion in the HSM are of the utmost quality for describing the characteristics of a particular road [AASHTO, 2010]. Figure 2.1 below provides recommended CMF values from Chapter 13 of the HSM for lane width on rural two-lane roadways.

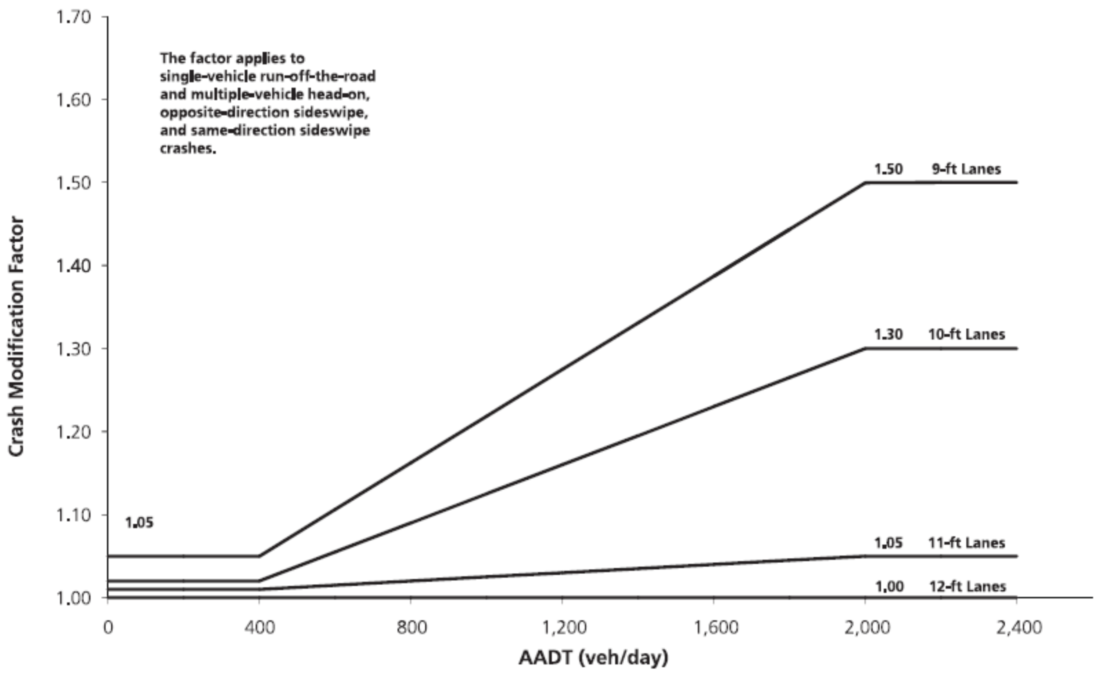

Figure 2.1: HSM CMFs for Lane Width on Rural Two-Lane Roadways [AASHTO, 2010]

These values indicate that for AADT values less than 400 veh/day, there is little variation between CMF values for lane width, which range from 1.0 to 1.05. As traffic volume increases on a particular roadway, the influence of changes in lane width on safety does as well. The CMF values range from 1.0 for the base condition to 1.5 for 9 ft lanes. In addition to lane width, Chapter 13 of the HSM also provides CMF values for changes in shoulder width on rural two-lane roadways. Figure 2.2 below shows recommended CMF values for shoulder width on rural two-lane roadways using a base condition of 6 ft. In addition, the spread in CMF values increases as AADT increases, with little variation for AADT values lower than 400 veh/day [Highway Safety Manual, 2010].

Gross et al. [2009] studied lane and shoulder widths on rural two-lane highways in Pennsylvania and Washington. Table 2.6 below provides a comparison of CMF values for lane and shoulder width combinations from the HSM, the study in Pennsylvania by Gross et al., and a similar study by Griffin and Mak [1987] at the Texas Transportation Institute.

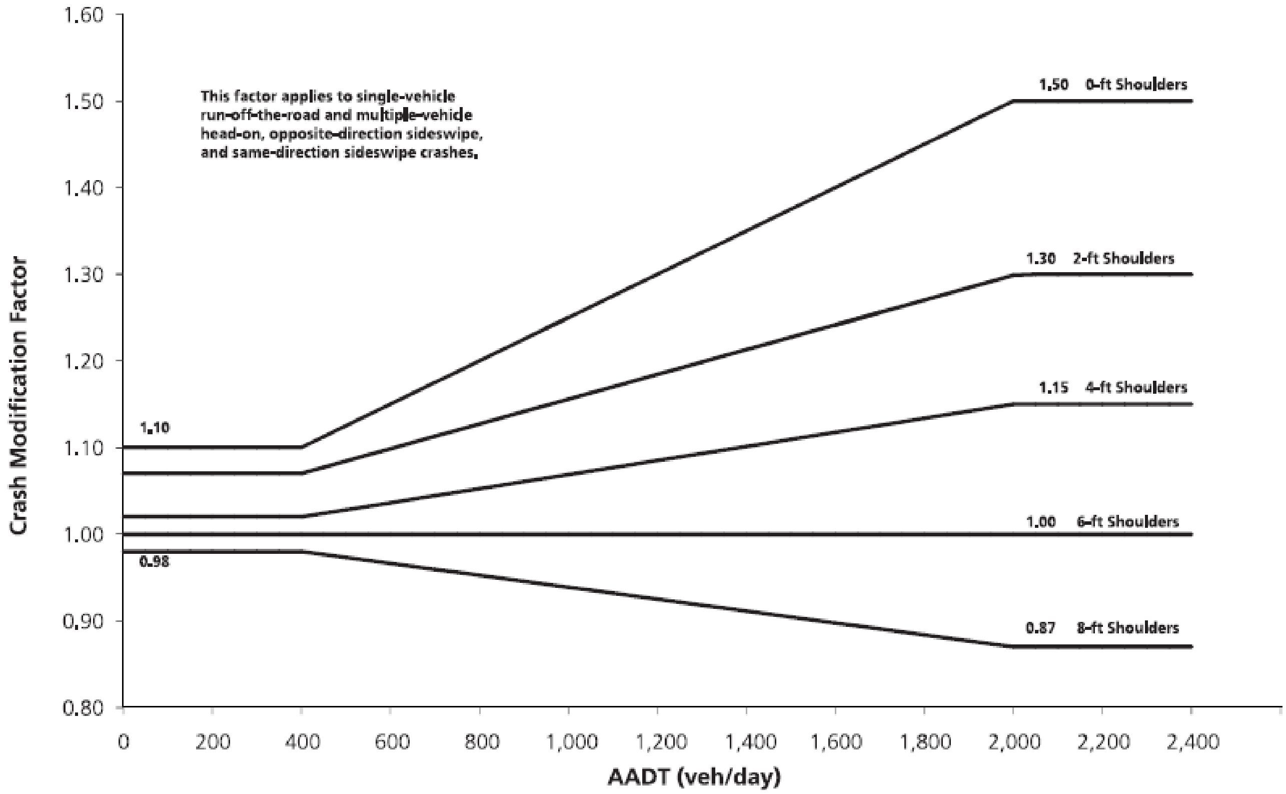

Figure 2.2: HSM CMFs for Shoulder Width on Rural Two-Lane Roadways [AASHTO, 2010]

Table 2.6: Comparison of Safety Studies on Rural Two-Lane Highways

Total Width (ft)	Lane Width (ft)	Shoulder Width (ft)	HSM CMF	TxDOT CMF	PA CMF
26	10	3	1.53	1.22	1.13
	11	2	1.36	1.13	1.12
	12	1	1.40	1.09	-
28	10	4	1.46	1.18	1.20
	11	3	1.29	1.10	1.19
	12	2	1.30	1.07	1.16
30	10	5	1.38	1.15	-
	11	4	1.22	1.07	1.14
	12	3	1.23	1.05	1.11
32	10	6	1.30	1.11	-
	11	5	1.14	1.05	1.06
	12	4	1.16	1.03	1.04
34	10	7	1.24	1.08	-
	11	6	1.06	1.02	0.84
	12	5	1.08	1.02	0.87
36	10	8	1.17	1.05	-
	11	7	1.00	1.00	-
	12	6	1.00	1.00	1.00

While Gross et al. [2009] studied roads in Pennsylvania and Washington, sample sizes in Washington were significantly smaller and resulted in less reliable CMF values. In addition to the CMFs verified by the HSM, the CMFs from the two studies in Table 2.6 were created to study the effect of lane and shoulder width on crash rate while controlling for confounding variables. In general, the effect of changes in the total width of the road on the crash rate is much higher for HSM CMFs than for the TxDOT and PA CMFs. Additionally, the CMF values in Table 2.6 indicate a slight benefit to increasing lane width compared with shoulder width for a fixed total available width. [Gross et al, 2009].

Because the HSM also considers many other confounding variables in analyzing the safety of rural two-lane roadways, this research must consider some of the generally accepted CMF values for these variables. For example, roadside hazard rating (RHR) can be an important predictor of crashes related to lane width on rural two-lane highways. Table 2.7 below provides a summary from Chapter 13 of the HSM for each of the descriptors for roadside hazard rating.

Table 2.7: Describing the Use of the Seven Roadside Hazard Ratings [AASHTO, 2010]

Rating	Clear zone width	Sideslope	Roadside
1	Greater than or equal to 30 ft	Flatter than 1V:4H; recoverable	N/A
2	Between 20 and 25 ft	About 1V:4H; recoverable	
3	About 10 ft	About 1V:3H or 1V:4H; marginally recoverable	Rough roadside surface
4	Between 5 and 10 ft	About 1V:3H or 1V:4H; marginally forgiving, increased chance of reportable roadside crash	May have guardrail (offset 5 to 6.5 ft) May have exposed trees, poles, other objects (offset 10 ft)
5		About 1V:3H; virtually non-recoverable	May have guardrail (offset 0 to 5 ft) May have rigid obstacles or embankment (offset 6.5 to 10 ft)
6	Less than or equal to 5 ft	About 1V:2H; non-recoverable	No guardrail Exposed rigid obstacles (offset 0 to 6.5 ft)
7		1V:2H or steeper; non-recoverable with high likelihood of severe injuries from roadside crash	No guardrail Cliff or vertical rock cut

There are seven total descriptors regarding the qualitative aspects of the roadside. All necessary offsets and clear zone widths are measured from the pavement edge line. Figure 2.3 below shows how RHR can be an effective tool for adjusting the CMF value associated with a particular roadway.

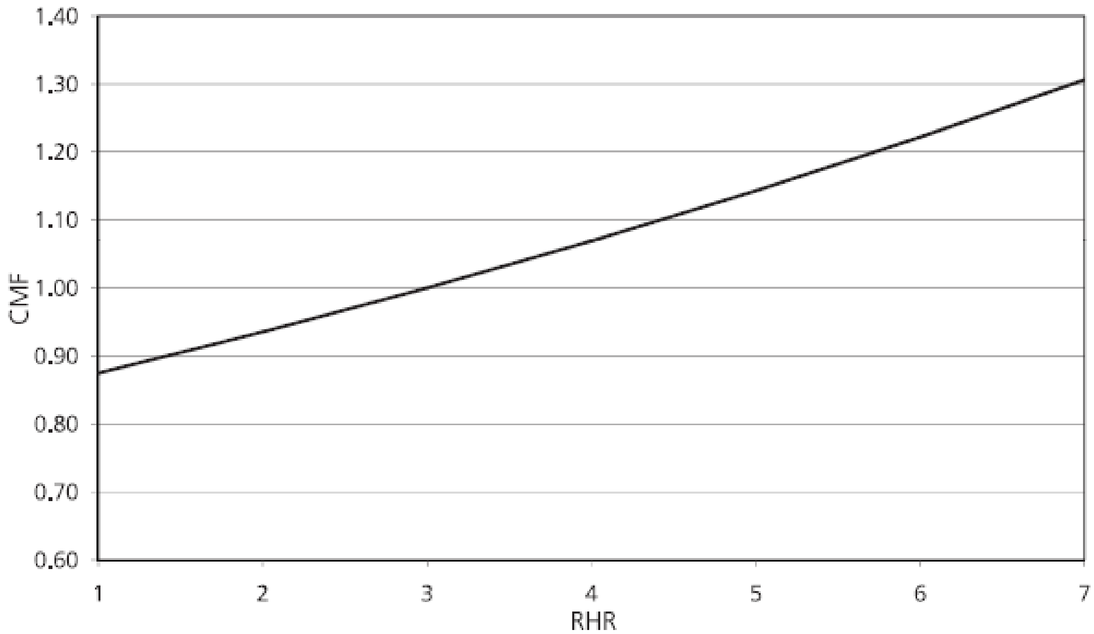

Figure 2.3: HSM CMFs for Roadside Hazard Rating on Rural Two-Lane Roadways [AASHTO, 2010]

In addition to RHR, driveway density on rural two-lane highways can be an important predictor of crashes. Chapter 13 of the HSM also provides input on the relationship between driveway density, AADT, and crashes on rural two-lane roads. Figure 2.4 below shows the potential effects of driveway density on CMFs for these roadways. The base condition, or the condition for which the CMF is 1, is considered to be 5 driveways (or access points) per mile.

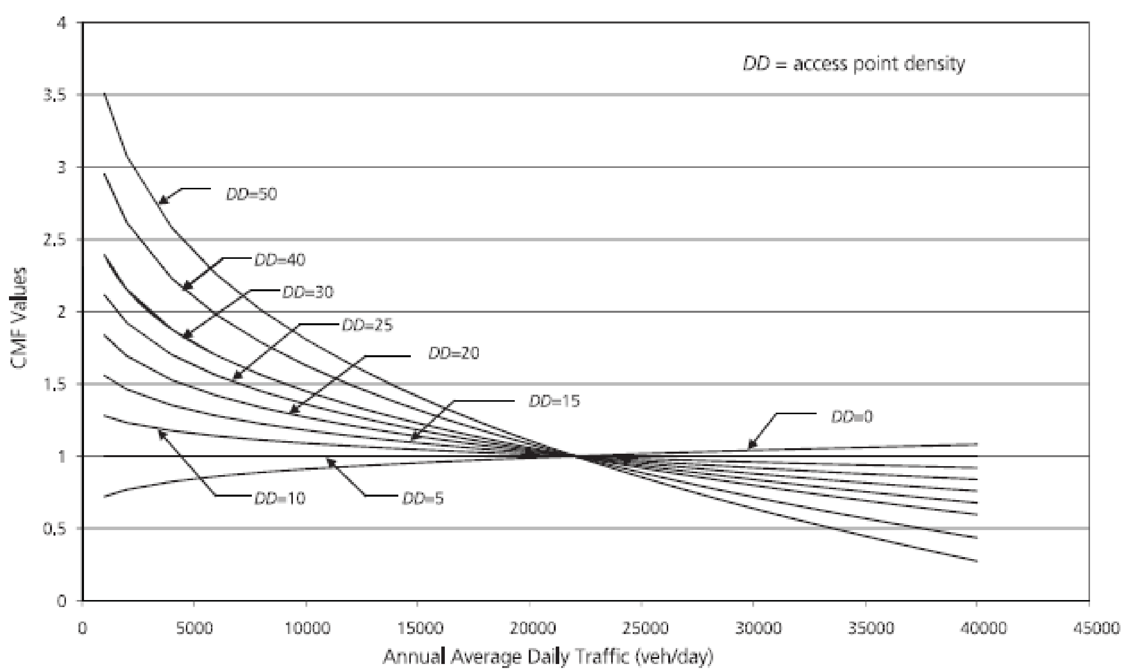

Figure 2.4: HSM Recommended CMFs for Driveway Density per mile [AASHTO, 2010]

Vertical grade can also help predict crashes on rural two-lane highways. The HSM provides CMFs for grades within a particular range. In considering vertical grade, the HSM applies the grade from one vertical point of intersection (VPI) to the next along a particular segment. Table 2.8 below summarizes the recommended CMF values from Chapter 13 of the HSM.

Table 2.8: HSM CMFs for Vertical Grade on Rural Two-Lane Highways [AASHTO, 2010]

Approximate Grade (%)		
Level Grade (≤ 3%)	Moderate Terrain (3%< grade ≤ 6%)	Steep Terrain (> 6%)
1.00	1.10	1.16

Understanding the many site conditions associated with a particular roadway is incredibly important to predicting crash frequency. By using generally accepted CMF values for variables like roadside hazard rating, driveway density and grade, designers can understand and anticipate changes in site conditions and apply them to the selection of lane widths on rural two-lane highways.

2.1.2.2 Rural Multilane Highways

Rural multilane highways are categorized into undivided four-lane roadway segments (4U) and divided four-lane roadway segments (4D) in Chapter 11 of the HSM. The definition for 4U segments encompasses all four-lane roadways with a continuous cross section, two-directions of travel, and lanes that are not separated by physical distance or barrier. Even though multilane roadways with opposing lanes separated by a flush median are considered undivided rather than divided facilities, the HSM models do not address multilane facilities with flush separators specifically. As for 4D segments, the HSM definition for these segments includes all non-freeway facilities with two-directions of travel that are separated by a median which is not designed to be traversed by vehicles. The median can be raised or depressed with or without a physical median barrier, or it can be flush with a physical median barrier. The HSM uses the following characteristics to analyze and predict crash frequency on rural multilane highways [AASHTO, 2010]:

1. AADT volume (vehicles per day)
2. Lane width
3. Shoulder width
4. Segment length
5. Presence of median and median width (feet) (for divided roadway segments)
6. Sideslope (for undivided roadway segments)
7. Presence/absence of lighting
8. Presence/absence of automated speed enforcement

Rural multilane highways are similar to two-lane highways regarding the relationship between lane width, paved shoulder width, and crash rate. Crash rate tends to follow an indirect relationship with both lane width and shoulder width. Figures 2.5 and 2.6 below provide HSM recommended CMFs for lane width on rural multilane highways.

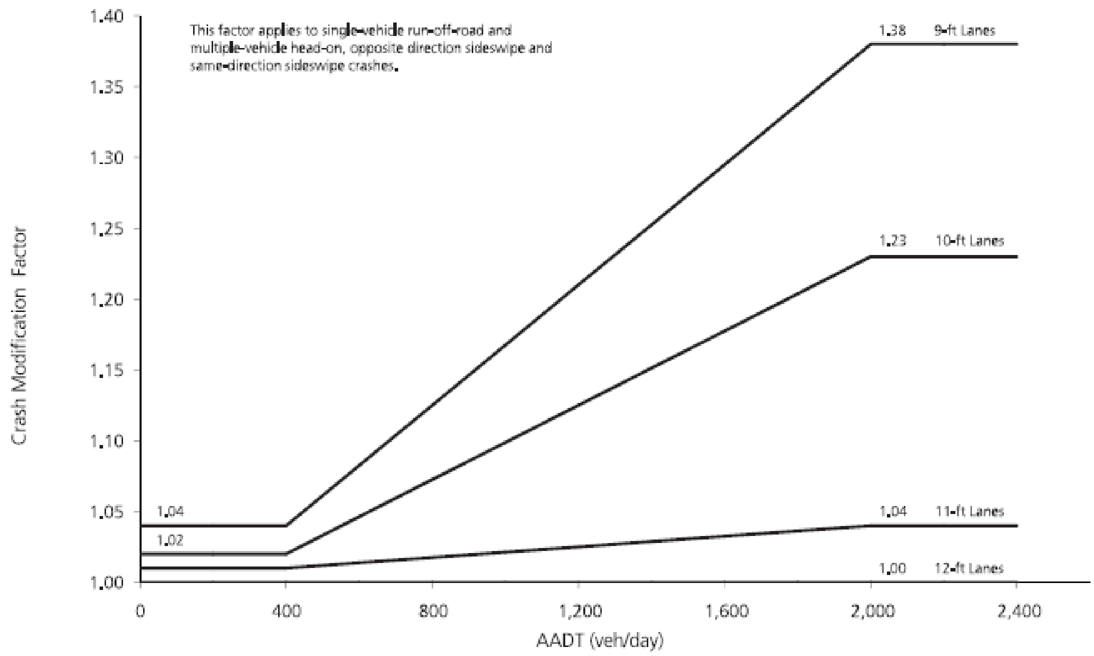

Figure 2.5: HSM CMFs for Lane Width on Undivided Rural Multilane Roadways [AASHTO, 2010]

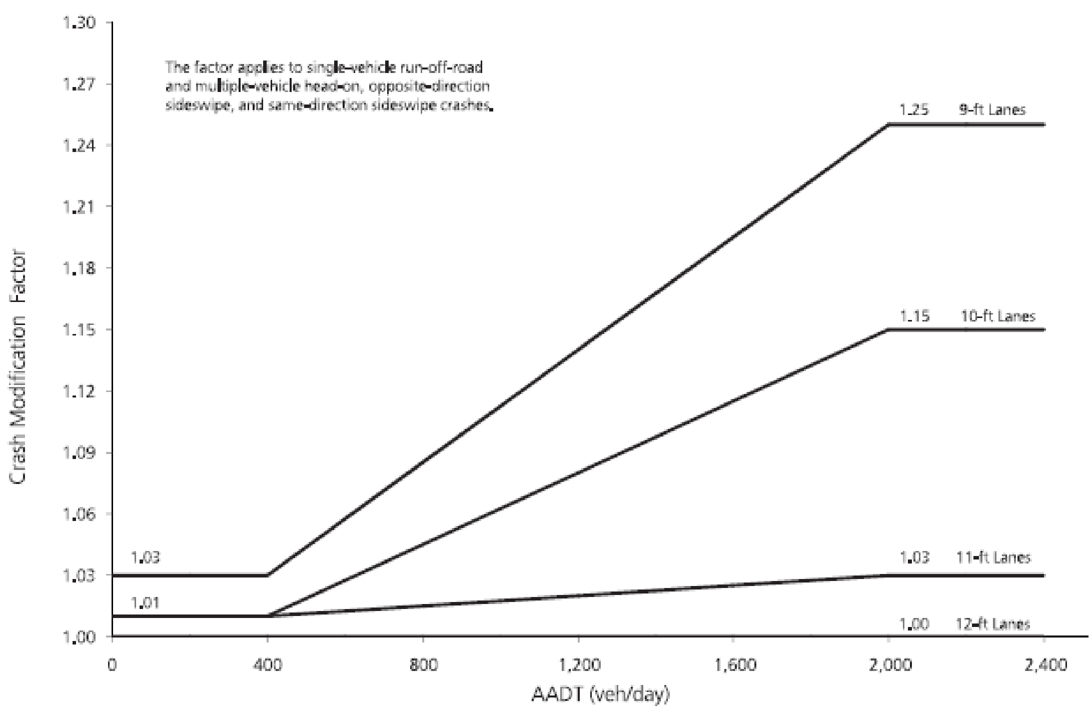

Figure 2.6: HSM CMFs for Lane Width on Divided Rural Multilane Roadways [AASHTO, 2010]

Similar to the recommended values for rural two-lane roads, there is little variation between CMF values for an AADT less than 400 veh/day. Stamatiadis et al. [2011] developed CMF values for average paved shoulder width on undivided and divided rural highways. The study was limited to four-lane roadways with 12 ft lanes. Table 2.9 below summarizes these results. The CMF values were developed for all crashes and severities. Additionally, the average shoulder width for undivided roadways is the average of the right shoulders, while the average shoulder width for divided roadways represents the average of the left and right shoulders in the same direction.

Table 2.9: Recommended CMF values for Shoulder Width on Rural Multilane Highways

Roadway	Shoulder Width (ft)						
	0	3	4	5	6	7	8
Four-lane Undivided (4U)	1.22	1.00	0.94	0.87	0.82	0.76	0.71
Four-lane Divided (4D)	1.17	1.00	0.95	0.90	0.85	0.81	0.77

Shoulder type can have an influence on collisions on rural multilane highways, but typically only for shoulders wider than 6 ft. The HSM provides CMF values for shoulder type and width on multilane highways. While paved shoulders are ideal, gravel shoulders are similarly effective. Relative to the base condition of 1.00 for paved shoulders, gravel shoulders have a CMF of 1.02 for 8 ft shoulders. Composite and turf shoulders tend to influence collisions more significantly, however, having 8 ft CMF values of 1.06 and 1.11, respectively [AASHTO, 2010].

Stamatiadis et al. (2011) also examined median width on divided rural highways and determined appropriate CMFs as width changed. The study's recommended CMF values were greater than those found in the HSM, which the study partly attributed to the fact that the results take only median width into account and not median barrier type. Typically, roadway sections with narrower medians have a barrier, but the study did not encounter enough data to sufficiently separate the various median barrier possibilities.

Table 2.10: Recommended CMF values for Median Width on Divided Highways

Category	Median Width (ft)							
	10	20	30	40	50	60	70	80
Multi-vehicle	1.00	0.91	0.83	0.75	0.68	0.62	0.57	0.51

Table 2.10 above displays the results of this study for multivehicle crashes, which was the only model analyzed with a significant statistic. The results indicate, as in the HSM, that crash rate reduces as median width increases [Stamatiadis, 2011].

2.1.2.3 Urban Highways

Chapter 12 of the HSM categorizes urban and suburban arterial roadways into groups based on number of travel lanes, divided or undivided operations, and presence of TWLTLs. The definition for 2U segments encompasses all two-lane roadways with a continuous cross-section, two-directions of travel, and lanes that are not separated by physical distance or barrier. For 3T segments, the HSM definition includes all three-lane roadways with a continuous cross-section, two-directions of travel, and directional lanes separated by a TWLTL. The HSM defines 4U segments as four-lane roadways with a continuous cross-section, two-directions of travel, and lanes that are not physically separated by distance or a barrier. Alternatively, 4D segments do have physical separation between opposing lanes by either distance or barrier. Unlike the definition of rural multilane segments, the HSM does not clearly indicate the extent to which multilane roadways with opposing lanes separated by a flush median are considered to be undivided versus divided facilities. Finally, the HSM definition for 5T segments includes all five-lane roadways with a continuous cross-section, two-directions of travel, and a center TWLTL [AASHTO, 2010]. Chapter 12 of the HSM uses the following characteristics to determine whether or not ideal conditions are satisfied for specific sites prior to crash prediction analysis on urban arterial roadway segments not including intersections [AASHTO, 2010]:

1. Length of roadway segment (miles)
2. AADT (vehicles per day)
3. Number of through lanes
4. Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
5. Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of street)
6. Number of driveways for each driveway type (major commercial, minor commercial; major industrial/institutional; minor industrial/institutional; major residential; minor residential; other)
7. Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a break-away design are counted)
8. Average offset to roadside fixed objects from edge of traveled way (feet)
9. Presence/absence of roadway lighting
10. Speed category (based on actual traffic speed or posted speed limit)
11. Presence of automated speed enforcement

Urban and suburban arterial roadways have been studied less frequently and comprehensively than have rural two-lane highways. Potts et al. [2007] performed a cross-sectional safety study to analyze the effect of lane width on safety for urban and suburban arterials in Minnesota and Michigan. The study found little indication that the use of narrower lanes increases crash frequency. Results suggest that geometric design policies, such as those described in the "Green Book," should indeed allow for flexibility in using lane widths narrower than 12 ft. Table 2.5 below describes the effect of lane width decrease from 11 and 12 ft to 9 and 10 ft for multiple- and single-vehicle crashes. The table separates urban and suburban arterials in Minnesota and Michigan by functional class and shows that none of the effects on crash type were statistically significant for a particular functional class in both states [Potts et al., 2007].

Table 2.11: Analyzing Lane Width and Crash Rate on Urban and Suburban Arterials [Potts et al., 2007]

Functional Classification	Setting	Effect of Lane Width Decrease from 11 and 12 ft to 9 and 10 ft in Minnesota	Effect of Lane Width Decrease from 11 and 12 ft to 9 and 10 ft in Michigan
2U	Urban	No Significance	No Change
2D/3T	Urban	Decrease	No Change
4U	Urban	Inconsistent	Inconsistent
4D	Urban	Increase	Inconsistent
5T	Urban	No Significance	Decrease

Additionally, Mbatta et al. [2012] developed lane width crash modification factors for urban multilane roadways with curb-and-gutter present. Mbatta et al. [2012] used urban 4D segments with a raised median as well as 5T segments. Similar to the Potts et al. [2007] study, this one sampled 25 centerline miles of 5T segments and 39 centerline miles of 4D segments to perform a cross-sectional safety study using six years of crash data. Furthermore, Mbatta et al. [2012] focused specifically on roadways with asymmetric lanes, where the outside lane is wider than the inside lane. The results of the study show that widening the outside lane from the base condition of 12 ft causes a reduction in estimated crash frequency for all crash categories on 4D and 5T segments. Additionally, reducing the inside lane width from 12 ft to 11 ft on 4D segments does not tend to affect estimated crash frequency, and the same is true for property damage only (PDO) crashes for 5T segments. However, the use of a narrower inside lane does tend to be associated with increased severe crashes for 5T segments.

TWLTLs can have a completely different impact on the roadway than normal travel lanes or shoulders, and the implementation of TWLTLs tends to greatly affect the safety of the roadway. Table 2.12 below provides a few countermeasures and their potential benefit for improving safety with the implementation of TWLTLs on urban arterials. For each of these studies, all lane width related crash types were considered.

While the presence of TWLTLs and the effect it can have on safety has been heavily researched, little research has been conducted relating TWLTL width and crash rate. Gattis et al. [2010] studied TWLTL widths between 9 ft and 13.5 ft and found no statistically significant relationship between TWLTL width and crash rate. However, a significant knowledge gap exists related to the impact of particular TWLTL widths on safety for varying functional classes and travel speeds on roadways. Thus, one of the main goals of this research is to create a usable, context-sensitive output for implementing TWLTLs in various settings in South Carolina.

Table 2.12: TWLTL Countermeasures on Urban Roadways

Conversion From:	**Conversion To:**	**Setting**	**Functional Classification**	**Expected Accident Reduction Rate (%)**	**Source**
Four lane undivided	Three-lane with TWLTL (Road Diet)	Urban	4U to 3T	**29**	HSM
Four-lane undivided	Five-lane with TWLTL (same total width)	Urban	4U to 5T	**44**	Harwood et. al, 1990
Four-lane divided with narrow median	Five-lane with TWLTL (same total width)	Urban	4D to 5T	**53**	Harwood et. al, 1990

2.1.3 Cross-Sectional Evaluation Method

To effectively evaluate the safety effects of various roadway treatments or geometric characteristics, one must choose a method appropriate for the available roadway data. Chapter 9 of the HSM provides guidelines for evaluating safety on roadways, and the most common method used for safety effectiveness evaluation consists of a before/after study [AASHTO, 2010]. While this type of evaluation would be preferred in establishing a relationship between lane width and safety, this is not particularly feasible in this type of study because of how agencies approach changes in the geometric characteristics of a roadway. Agencies rarely change the lane width, shoulder width, or any particular variable without making additional changes that would alter the results of any evaluation process [Potts et al, 2007].

As a result, a cross-sectional safety evaluation is more appropriate for samples with insufficient "before/after" data. This evaluation method determines the effect of different treatments by grouping similar sites by attributes and comparing treatment sites to comparable non-treatment sites. The HSM recommends 10 to 20 treatment and non-treatment sites as well as 3 to 5 years of crash data for both treatment and non-treatment sites [AASHTO, 2010]. Potts et al. [2007] followed this safety evaluation procedure and developed negative binomial regression models to evaluate the effectiveness of different lane width combinations on urban and suburban arterials. This research replicates to a certain extent the methods used by Potts et al.

2.1.4 Operational Effects of Lane Width

Lane width can have a significant impact on many of the operational characteristics of the roadway, including free-flow speed (FFS) along a segment and saturation flow rate at signalized intersections. The *Highway Capacity Manual* (HCM) summarizes research on the use of lane width, paved shoulder width, and median type to predict changes in FFS on two-lane and multilane highways.

Table 2.13 provides HCM free-flow speed reductions for potential changes in lane and shoulder width on two-lane highways. These values indicate that the use of flexibility in selecting lane and shoulder widths can potentially contribute to the reduction of speeds on a roadway. Additionally, reducing speeds can provide context-sensitive benefits, such as improved operational harmony between vehicles, pedestrians, and bicycles along a roadway. The HCM also provides FFS reductions for multilane highways, considering both lane width and median type. Table 2.14 below summarizes these results.

Table 2.13: Free-flow Speed Reductions on Two-Lane Highways (mph) [TRB, 2010]

Lane Width (ft)	**Shoulder Width (ft)**			
	0 to 2	2 to 4	4 to 6	≥ 6
9 to 10	**6.4**	**4.8**	**3.5**	**2.2**
10 to 11	**5.3**	**3.7**	**2.4**	**1.1**
11 to 12	**4.7**	**3**	**1.7**	**0.4**
> 12	**4.2**	**2.6**	**1.3**	**0**

Table 2.14: Free-flow Speed Reductions on Multilane Highways (mph) [TRB, 2010]

		FFS Reduction (mph)
Lane Width	>12	**0**
	11-12	**1.9**
	10-11	**6.6**
Median Type	Undivided	**1.6**
	TWLTL	**0**
	Divided	**0**

Additionally, lane width can impact saturation flow rate at signalized intersections. Potts et al. [2007] found only a 5% reduction in saturation flow rate for 10 ft lanes versus the base condition of 12 ft lanes. Similarly, the HCM saturation flow rate adjustment is the same for lanes between 10 and 12.9 ft, with only minor changes for lanes below 10 ft or above 12.9 ft. The complete saturation flow rate adjustment factors are available in Table 2.15 below.

Table 2.15: Saturation Flow Rate (1900 pc/h/ln) Adjustment Factors for Lane Width [TRB, 2010]

Average Lane Width (ft)	Adjustment Factor (f_w)
<10.0	0.96
≥10.0-12.9	1
>12.9	1.04

For these adjustment factors, the minimum lane width is 8 ft. Additionally, lanes greater than 16 ft can be analyzed, but it should be considered whether or not the lane functions as two narrow lanes [TRB, 2010].

2.1.5 Driver Behavior and Perceived Lane Width

The previously mentioned studies demonstrate the various ways in which lane width can affect the safety and operation of roadways, but in reality, these relationships only exist because different lane widths have an effect on the behavior of different driver types and how they perceive the roadway. For example, Mohamed and Radwan [2000] found that female drivers tend to experience more accidents in conditions with reduced lane width, reduced median width, heavy traffic volume, and a larger number of lanes than do male drivers. In addition, young and old drivers were subject to higher crash frequencies compared to middle age drivers. Because driver type can be an important element affecting the occurrence of accidents on a roadway, it is important to consider all of the effects of potential design changes involving road width.

Many studies have confirmed the general trend that narrower lane widths result in slower travel speeds. Godley et al. [2004] stated two hypotheses to explain this speed reduction:

1. Drivers perceive a higher risk of a potential accident when travelling on narrower lanes and therefore will slow down to reduce the risk of an accident.

2. Maintaining a high speed on narrower lanes requires greater mental effort, so drivers tend to slow down to allow themselves to stay in a relatively relaxed mental state.

The inverse relationship between lane width and crash frequency accepted by many on rural two-lane highways creates a design tradeoff between narrower lanes with lower speeds but higher crash rates. Godley et al. [2004] attempted to solve this tradeoff using driver simulator experiments by reducing the perceived lane width instead of the physical lane width. Perceived lane width is different from actual lane width because it can be adjusted through the use of pavement markings whereas actual widths are based on asphalt measurements. Ogden [1996] suspected that the probability of a run-off-the-road or head-on accident is indirectly related to the distance between vehicles and the lane boundaries, making perceived lane width incredibly important. The perceived lane markings such as a widened centerline or gravel marking were found to effectively reduce driving speeds in Godley's study [Godley et al, 2004]. This represents one possible solution to the safety issues created by narrow lanes forcing vehicles closer together. By reducing the perceived lane width but not the actual width of the roadway, speeds are reduced without increasing the occurrence of crashes because drivers still maintain the same amount of space for maneuvering.

2.1.6 Summary of Literature Review

This review compiles research focused on lane widths and the effect of different design alternatives on the operation and safety of roadways. Designers today are facing new challenges in recommending lane widths for various combinations of site location conditions, traffic volume, functional classification, and design speed. Even though AASHTO identifies a flexible range from which lane widths can typically be selected for specific site conditions, some State DOTs have policies in place that restrict the selection of lane widths less than 12 ft for new projects [Kueper, 2010]. Thus, there exists a lack of application, particularly in South Carolina, related to the use of context-sensitive design in selecting lane widths. Previous research has shown that the situational use of narrower lanes through a context-sensitive approach can lead to lower construction costs in addition to more sustainable and livable streets [Potts et al, 2007]. By applying this approach to roads in South Carolina, these benefits can potentially be achieved without compromising the safety of these facilities.

In determining the safety effects of different lane widths on rural and urban highways, it is important to consider the types of crashes being analyzed for the study. The HSM, based on years of research, generally accepts that single vehicle-run-off-the-road, multiple vehicle head-on, as well as same- and opposite-direction sideswipe crashes tend to be most influenced by lane width [Highway Safety Manual, 2010]. In addition to the types of crashes being considered for lane width analysis, different types of rural highways behave independently when it comes to lane width analysis. As a result, this research considers the effect of crashes on rural two-lane highways separately from the effect on rural multilane roads in South Carolina. Researchers, such as Harwood et al. [2000] and Gross et al. [2009], have made great strides in defining some of the most relevant relationships between lane width, paved shoulder width, and safety on rural highways. Generally, both two-lane highways and multilane highways tend to follow an inverse relationship between lane width and safety, meaning that narrower lanes tend to increase crash rate. However, there still exists the potential for flexibility in design based on design speed, traffic volume, or other site conditions such as the presence of shoulders, grade, driveway density, or roadside features. One type of analysis that has been beneficial in analyzing groups of road segments with many different site conditions is the cross-sectional safety evaluation. Potts et al. [2007] used this safety evaluation procedure to analyze the influence of lane width on the safety of urban and suburban arterials in Michigan and Minnesota.

In addition to the physical attributes of the road, driver behavior must also be considered in analyzing the safety effects of lane widths. Responses to changes in lane width can vary depending on the type of driver as well. Studies involving field and simulator tests have demonstrated how driver behavior can be used to a designer's advantage because reducing the perceived lane width can effectively reduce speeds without increasing the risk of a crash [Godley et al, 2004]. Knowing the impact of driver behavior on safety can be a helpful tool when developing recommendations for lane width design standards.

Ultimately, the purpose of this research, in accordance with many of the previously mentioned studies, is to evaluate the effect of lane width on safety while considering many of the confounding variables and site conditions present on South Carolina roadways. Designers face many new challenges related to the recommendation of lane widths for a particular facility. As a result, the design process must become more context-sensitive. Flexibility helps designers by allowing them to make decisions appropriate to setting and environment. By developing a definitive safety study in South Carolina, this research can help identify how flexibility in design can be utilized.

2.2 Survey of States

2.2.1 Comparison of DOT Highway Design Manuals

Highway design manuals for nearly all of the state DOTs' in the US were reviewed to determine how South Carolina highway design standards compare to the range of lane width and related typical section design values used by other agencies. A detailed review of values was limited to states that provide their design manuals on-line and organize required data in a manner that could be extracted and compared side-by-side with South Carolinas' design standards for rural/urban arterials and collectors. South Carolinas' standards for rural highways are summarized in Chapter 20 of the Highway Design Manual, and for urban highways in Chapter 21. Requirements included in state DOT highway design standards closely parallel AASHTO "Green Book" guidelines, specifically cited as A Policy on Geometric Design of Highways and Streets, 6th Edition, American Association of State Highway and Transportation Officials. Most state DOTs' have different design standards related to lane width, shoulders, auxiliary lanes, turn lanes, two way left turn lanes, medians, etc. for 3R (resurfacing, restoration and rehabilitation) and 4R (resurfacing, restoration, rehabilitation and reconstruction) roadway projects. Lane width design criteria for each of the five target roadway classifications is identified and discussed in the following sections.

2.2.2 Rural Two-Lane Arterials

A list of 13 DOT's included in the detailed review of lane width values for rural two-lane arterials are summarized in Table 2.16. Width dimensions are compared with values provided in SC DOT HDM Chapter 20, Figure 20.1D, Geometric Design Criteria for Rural Two-Lane Arterials. AASHTO and six of the DOT's included in the survey of states allow a range of 11-12 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. With regard to shoulder width, four of the DOT's included in the survey of states require paved shoulder widths greater than two feet as identified in AASHTO and SC DOT HDM criteria.

Table 2.16: Rural Two-Lane Arterial, Comparison of Lane Width Design Criteria

Agency	Travel Lane Width (ft.)	Shoulder Width (ft.)
AASHTO	11-12	4-8 (2 paved)
SC DOT (HDM)	12	10 (2 paved)
Georgia	11-12	4-8 (2 paved)
N. Carolina	11-12	4-8
Texas	12	4-10
Florida	12	8-12 (5 paved)
Ohio	11-12	8-12 (4-8 paved)
Oregon	11-12	4-8
Washington	12	4-10
Indiana	12	6-11 (4-10 paved)
Illinois	11-12	11-12 (4 paved)
Michigan	11-12	4-8
Connecticut	12	4-8
Maine	12	4-10
Wisconsin	12	4-8

2.2.3 Rural Two-lane Collectors

A list of 13 DOT's included in the detailed review of lane width values for rural two-lane collectors are summarized in Table 2.17. Width dimensions are compared with values provided in SC DOT HDM Chapter 20, Figure 20.1E, Geometric Design Criteria for Rural Two-Lane Collectors. AASHTO and nine of the DOT's included in the survey of states allow a range of 10-12 feet for travel lane width design criteria versus a range of 11-12 feet identified in SC DOT HDM criteria. With regard to shoulder width, four of the DOT's included in the survey of states require paved shoulder widths greater than two feet as identified in AASHTO and SC DOT HDM criteria.

Table 2.17: Rural Two-Lane Collector, Comparison of Lane Width Design Criteria

Agency	Travel Lane Width (ft.)	Shoulder Width (ft.)
AASHTO	10-12	2-8
SC DOT (HDM)	11-12	6-8
Georgia	10-12	2-8
N. Carolina	10-12	2-8
Texas	10-12	2-10
Florida	11-12	8-12 (5 paved)
Ohio	10-12	6-10 (4-8 paved)
Oregon	10-12	2-8
Washington	12	4-8
Indiana	10-12	4-10 (2-8 paved)
Illinois	11-12	11-12 (4 paved)
Michigan	10-12	2-8
Connecticut	10-12	2-8
Maine	10-12	4-8
Wisconsin	12	4-8

2.2.4 Rural Four-Lane Arterials

A list of 13 DOT's included in the detailed review of lane width values for rural four-lane arterials are summarized in Table 2.18. Width dimensions are compared with values provided in SC DOT HDM Chapter 20, Figure 20.2C, Geometric Design Criteria for Rural Four-Lane Arterials. AASHTO and five of the DOT's included in the survey of states allow a range of 11-12 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. With regard to shoulder width, four of the DOT's included in the survey of states require paved shoulder widths greater than two feet as identified in AASHTO and SC DOT HDM criteria.

Table 2.18: Rural Four-Lane Arterial, Comparison of Lane Width Design Criteria

Agency	**Travel Lane Width (ft.)**	**Shoulder Width (ft.)**
AASHTO	11-12	8 (2 paved)
SC DOT (HDM)	12	10 (2 paved)
Georgia	11-12	8 (2 paved)
N. Carolina	11-12	4-8
Texas	12	4-10
Florida	12	8-12 (5 paved)
Ohio	11-12	8-12 (4-8 paved)
Oregon	12	8
Washington	12	8-10
Indiana	12	11 (10 paved)
Illinois	11-12	11-12 (4 paved)
Michigan	11-12	4-8
Connecticut	12	4-8
Maine	12	10
Wisconsin	12	8

2.2.5 Suburban/Urban Arterials

A list of 12 DOT's included in the detailed review of lane width values for Suburban/Urban arterials are summarized in Table 2.19. Width dimensions are compared with values provided in SC DOT HDM Chapter 21, Figure 21.3A, Geometric Design Criteria for Suburban/Urban Arterials. AASHTO and three of the DOT's included in the survey of states allow a range of 10-12 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. Additionally, seven of the DOT's allow a range of 11-12 feet for travel lane width design criteria. With regard to two way left turn lane (TWLTL) width, AASHTO and four of the DOT's included in the survey of states allow a lower limit of 11 feet, two of the DOT's allow a lower limit of 10 feet, and two of the DOT's allow a lower limit of 12 feet. In total, eight of the DOT's included in the survey of states allow a lower limit of 12 feet, or less, versus a minimum value of 15 feet identified in SC DOT HDM criteria. With regard to auxiliary lane widths, AASHTO and eight of the DOT's included in the survey of states allow a lower limit of 10 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. Median, shoulder, and parking lane width criteria vary considerably as shown in Table 2.19.

2.2.6 Suburban/Urban Collectors

A list of 12 DOT's included in the detailed review of lane width values for Suburban/Urban arterials are summarized in Table 2.20. Width dimensions are compared with values provided in SC DOT HDM Chapter 21, Figure 21.3C, Geometric Design Criteria for Suburban/Urban Collectors. AASHTO and six of the DOT's included in the survey of states allow a range of 10-12 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. Additionally, six of the DOT's allow a range of 11-12 feet for travel lane width design criteria. With regard to two way left turn lane (TWLTL) width, AASHTO and four of the DOT's included in the survey of states allow a lower limit of 11 feet, two of the DOT's allow a lower limit of 10 feet, and two of the DOT's allow a lower limit of 12 feet. In total, eight of the DOT's included in the survey of states allow a lower limit of 12 feet, or less, versus a minimum value of 15 feet identified in SC DOT HDM criteria. With regard to auxiliary lane widths, AASHTO and eight of the DOT's included in the survey of states allow a lower limit of 10 feet for travel lane width design criteria versus a minimum value of 12 feet identified in SC DOT HDM criteria. Median, shoulder, and parking lane width criteria vary considerably as shown in Table 2.20.

2.2.7 Unique state DOT approaches to Lane Width Design Criteria

With a renewed interest from policymakers, elected officials, special interest groups, and the general public in topics such as context sensitive solutions, road diets, traffic calming, complete streets, and project right-sizing, many state DOT's have adopted procedures to allow increased flexibility in selection of roadway design criteria, especially in suburban and urban areas where differing modes of travel share the same right-of-way. A few relevant state DOT approaches are summarized as follows:

Michigan DOT – A 2003 executive directive (Governor's Executive Directive 2003-25) instituted context sensitive design for transportation projects in Michigan and lead to creation of a number of related documents including a memorandum that outlines flexibility in application of design standards for roadways that are appropriate for context sensitive solutions. Design exceptions are predicated upon 13 specific controlling criteria as identified in FHWA's Mitigation Strategies for Design Exceptions. When design criteria cannot be met within the specified ranges, designs outside the range may be considered but documentation including crash analyses must justify alternative designs. A corridor approach is used for planning, multimodal and related route features as implemented through an interdisciplinary team working in partnership with local authorities.

Florida DOT – Chapter 14 in Florida DOT's Manual of Uniform Minimum Standards for Design, Construction and Maintenance for Streets and Highways describes very specific procedures for documenting and approving design exceptions based upon 13 specific controlling criteria. Justification and documentation of design exceptions include: specific project conditions related to design exception, controlling design element, acceptable Manual value, and proposed value for project. Additionally, the design exception must address compatibility of the design and operation with adjacent sections, amount and character of traffic using facility, effect on capacity, safety impacts and benefit cost analysis.

North Carolina DOT – Guidelines for preparing a design exception request are provided based upon 13 specific controlling criteria. The process documents the economic, physical, social or environmental restraints that prevent the application of specific highway design criteria or standard. Approval acknowledges that fulfilling a particular design standard requires an unreasonable expense or impact due to special or unusual conditions on the project.

Table 2.19: Suburban/Urban Arterial, Comparison of Lane Width Design Criteria

Agency	Lane Width (ft.)	TWLTL Width (ft.)	Median Width (ft.)	Flush Median Width (ft.)	Shoulder Width (Ft.)	Aux. Lane Width (ft.)	Parking Lane Width (ft.)
AASHTO	10-12	11-16	12-18	2-4	2-8	10-12	10-12
SC DOT (HDM)	12	15	36	4-12	10 (2 paved)	12	10-12
Georgia	10-12	14	20-44	14	2-8	10-12	10-12
N. Carolina	10-12	11-16	16-60	2-4	4-8	10-12	10-12
Texas	11-12	14-16	4-76	16	4-10	10-12	10-12
Florida	12	10-15	22-50	10-12	8-12 (5 paved)	10-12	8-12
Ohio	11-12	10-14	4-40	10-14	8 (2 paved)	10-12	7-10
Oregon	11-12	14	4-16	6-10	5-6 paved	12	7-12
Washington	11-12	11-13	3-46	10-12	8-12	11-12	10
Indiana	10-12	12-16	26.5-50	4-16	6-10 paved	10-12	10-12
Illinois	11-12	11-13	18-50	11-13	10 paved	10-12	10
Connecticut	11-12	11-12	50-90	8-20	4-8	11-12	10-11
Maine	12	12-16	6-18	2-6	2-10	11-12	10-12
Wisconsin	11-12	13	18-46	2-13	10	10	10

Table 2.20: Suburban/Urban Collector, Comparison of Lane Width Design Criteria

Agency	**Lane Width (ft.)**	**TWLTL Width (ft.)**	**Median Width (ft.)**	**Flush Median Width (ft.)**	**Shoulder Width (Ft.)**	**Aux. Lane Width (ft.)**	**Parking Lane Width (ft.)**
AASHTO	10-12	10-16	18-25	2-16	2-8	10-12	8-11
SC DOT (HDM)	12	15	36	4-12	10 (2 paved)	12	8-12
Georgia	10-12	14	20-44	14	2-8	10-12	8-11
N. Carolina	10-12	10-16	16-60	2-16	4-8	10-12	8-11
Texas	10-12	11-16	4-76	16	3-8	10-12	7-10
Florida	11-12	10-15	22-40	10-12	8-12 (5 paved)	10-12	8-12
Ohio	10-12	10-14	4-40	10-14	1-2 paved	10-12	7-11
Oregon	11-12	14	4-16	6-10	5-6 paved	12	7-12
Washington	11-12	11-13	3-46	10-12	4-8	11-12	10
Indiana	10-12	12-16	4-18	4-16	6-8 paved	10-12	8-11
Illinois	11-12	11-13	18-50	11-13	10 paved	11-12	10
Connecticut	10-12	11-12	8-20	8-20	2-8	11	8-10
Maine	11-12	12-14	6-18	2-6	6-8	10-12	7-10
Wisconsin	11-12	13	18-46	2-13	8-10	10	10

Oregon DOT – The Highway Design Manual includes three special designations for roadway design criteria. These special designations are in addition to commonly used rural and suburban/urban arterial and collector roadway design criteria and address numerous guidelines for lane widths, access management, parking, pedestrians, bike lanes and traffic calming. Special designations include: Special Transportation Areas (STAS), Urban Business Areas (UBAs), and Commercial Centers (CCs). These special designations are briefly summarized as follows:

- Special Transportation Areas (STAS), The primary objective of a STA is to provide access to community activities, businesses, and residences, and to accommodate pedestrian, bicycle, and transit movement along and across the highway. Providing and encouraging a well-designed pedestrian, bicycle, and transit friendly environment is a major goal of the designer in these areas. This generally means that through traffic operations and efficiency may be reduced in order to improve the attractiveness and operations of other modes of travel. STAS must be identified within a local comprehensive plan, transportation system plan (TSP), corridor plan, or refinement plan, and adopted by the Oregon Transportation Commission. STA characteristics and attributes include: well-developed parallel and interconnected local roadway network, adjacent land uses that provide for compact, mixed use development, on street parking, and well-developed transit, bicycle and pedestrian facilities. Travel lane width criteria range from 10-12 feet and design speeds from 25-30 mph.
- Urban Business Areas (UBAs), Urban Business Areas (UBAs) are areas within urban growth boundaries where commercial activity is located along the highway and where vehicular accessibility is important to economic vitality. The primary objective of the state highway in an UBA is to maintain existing traffic speeds while balancing the access needs of abutting properties with the need to move through traffic. UBA characteristics and attributes include: intersections designed to address the needs of pedestrians and bicyclists, provision of transit stops, and inter-parcel circulation. Travel lane width criteria range from 11-12 feet and design speeds are generally 35 mph or greater.
- Commercial Centers (CCs), A Commercial Center designation may apply to an existing or future center of commercial activity that generally has 400,000 square feet or more of gross leasable area or public buildings. Commercial Centers generally are intended to serve the local community, but many centers provide a regional draw. The state highway and supporting road network must accommodate all travel modes and provide accessibility and circulation to pedestrian, bicycle, and, where appropriate, transit users. CC characteristics and attributes include: Shared parking and a reduction in parking to accommodate multimodal elements where alternate modes are available, compact development patterns, accessibility by a variety of routes and modes, and integration with the local road network.

3.0 DATA COLLECTION AND ANALYSIS METHODOLOGIES

The purpose of this research is to identify the safety and operational characteristics associated with the widths of South Carolina roadways, specifically with respect to lane width and shoulder width. By quantitatively and qualitatively analyzing roads in South Carolina from safety and operational perspectives, this research offers specific recommendations to the existing design standards for roadway width. This chapter describes the methods used in this research. The sections of this chapter include a description of the initial data sources, an explanation of the inventory and data collection process, and the methodology used to analyze selected routes.

3.1 Project Commencement

The Clemson research team participated in several introductory strategy sessions with SCDOT early in the project to discuss necessary tasks to be undertaken and important data to be provided by SCDOT at the onset of the project. The project team developed a framework for obtaining crash databases from 2007 to 2009 from SCDOT. In addition, geometric characteristics were from the SCDOT Roadway Information Management System (RIMS) data. Roadway segment digital shapefiles for South Carolina are readily available on the SCDOT website in the GIS and Mapping section [SCDOT, 2011]. After obtaining the appropriate shapefiles, geometric data from the RIMS database was linked spatially to individual segments using a unique route LRS and beginning mile point (BMP). Obtaining RIMS data and assigning attributes to individual segments proved to be critical for categorizing roadway attributes and selecting case study sites.

3.2 Technology Tools and Software Tools

Several software packages and mobile data collection equipment were used throughout the project for roadway data collection and analysis. The process of categorizing road segments by lane widths and configuration and verifying attributes of these segments began using software packages provided at the SCDOT Pickens County Office and followed with on-site software at Clemson University.

- Microsoft Excel and Access
- SCDOT RIMS Photolog Viewer
- Google Earth Software by Google
- ArcGIS 10 by Esri
- Bing Aerial Maps
- Maptitude Software by Caliper Corporation (GIS)

Geometric roadway data was collected in the field using Clemson's Mobile Transportation System Laboratory (MTSL), an instrumented-research vehicle equipped with the following:

- Trimble AgGPS 132 Global Positioning System (GPS)
- Acuity AR4000 Laser Rangefinder and Line Scanner from Schmitt
- Measurement Systems, Inc.
- Vehicle-Mounted FireWire Cameras
- On-Board Computers
- V-Log software from Clemson University (mobile photologging system)

Office processing of the MTSL collected data was conducted using custom MATLAB routines. After data collection was completed, a cross-sectional analysis of these segments was performed using "R" Statistical Software, Version 2.15.2 by Kurt Hornik

Various equipment was also used in the collection of field data including distance measuring devices, stop watches, and vehicle counting and safety equipment.

3.3 Initial Segment Inventory and Selection

3.3.1 Preliminary Roadway Segment Inventory

Once all relevant data resources were obtained, the identification of appropriate sites for data collection and analysis became the primary focus of the research team. Initial meetings with SCDOT revealed that grouping analysis sites would be necessary to create pools of segments with identical geometric properties. A target sample size of 30-40 segments per pool was decided upon because such a sample size improves the significance of the results produced by a statistical analysis. In addition, it was determined that each segment should meet certain requirements to ensure that the analysis produced meaningful results. These requirements included the following:

- Each segment should be at least 0.1 mi in length. Segments shorter than 0.1 mi in the RIMS database are often identified as intersection approaches or transition zones. Also, the random assignment of crashes to small segments creates too large of variability in the models used for crash analysis.
- Segments chosen for analysis should be uniform from beginning to end. Geometric changes within a segment such as an increase or decrease in pavement width, the addition or removal of a shoulder, and the presence of auxiliary lanes can all impact the number of crashes along a roadway segment and should therefore be avoided to ensure that all segments in a particular pool are homogeneous.
- Segments with significant horizontal curvature were initially avoided, as the frequency of incidents tends to increase as the number of horizontal curves along a segment increases. However, the team did make some consideration for using segments with curves on rural two-lane roadways in the later stages of the project. Using only non-curved sections of roadway can affect the random assignment of crashes to segments. As described in Chapter 4, very few crashes occurred across the entire non-curved sample.
- Segments should not pass through intersections. Vehicles turning, slowing, or stopping at intersections can all cause incidents that should not be included when analyzing the impact of lane width on safety.
- Segments should not include bridge sections. Roadway segments that traverse bridges often behave differently due to the presence of physical barriers, which are typically rigid and in closer proximity to the travel lanes.

Nine counties in South Carolina were ultimately chosen for data collection: Beaufort, Horry, Jasper, Lexington, Orangeburg, Pickens, Richland, Spartanburg, and York. These counties were selected to provide an even mix of Upstate, Midlands, and Coastal conditions, as displayed in Figure 3.1 below, so that the final sample would be representative of the entire state of South Carolina.

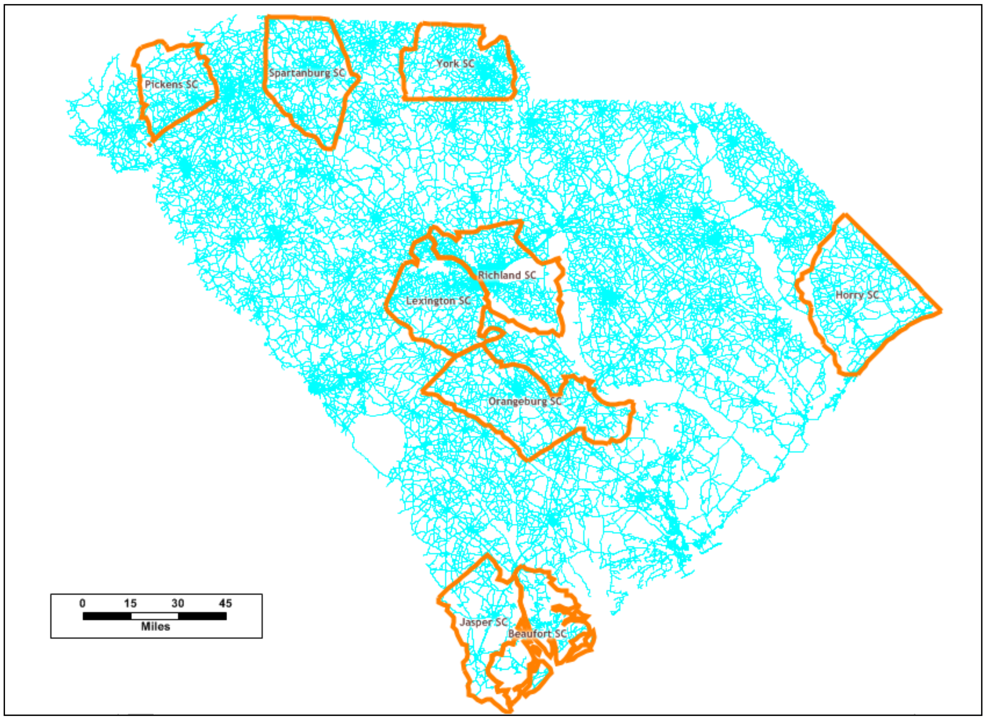

Figure 3.1: Counties Selected for Inventory Sample

A preliminary list of 33 different categories for rural and urban roadway segments was developed (see Table 3.1), with each category consisting of one specific combination of area and geometric attributes. A segment that met the requirements of any one of these categories was considered as a potential candidate for analysis. These categories were created based on a combination of available attributes in the RIMS database, including functional classification, median type, lane width, and the presence or absence of curb and gutter along the roadway. Out of these four attributes, only lane width could not be directly determined from the RIMS database. Using the provided total pavement width, along with other values such as number of through lanes, median type, median width, shoulder type, and shoulder width, the lane width could be estimated for each segment in the database. However, this did not allow enough precision to comfortably determine lane width groupings, as numerous segments included excess lane width due to wide outside lanes or on-street parking. As a result, lane width groups were not determined until the data processing was completed. Table 3.2 provides a breakdown of the total mileage across the state of South Carolina by the 33 original categories.

Table 3.1 Initial Analysis Categories based on Area and Geometric Characteristics

Category	Rural or Urban	Shld/Median/CG	Lane Width (ft)	Width Category (ft)
1	Rural	No Shoulder	9.5’ ≤ Lanes < 10.5’	10
2	Rural	No Shoulder	10.5’ ≤ Lanes < 11.5’	11
3	Rural	No Shoulder	11.5 ≤ Lanes ≤ 12’	12
4	Rural	Shoulder ≤ 4’	9.5’ ≤ Lanes < 10.5’	10
5	Rural	Shoulder ≤ 4’	10.5’ ≤ Lanes < 11.5’	11
6	Rural	Shoulder ≤ 4’	11.5 ≤ Lanes ≤ 12’	12
7	Rural	Shoulder > 4’	9.5’ ≤ Lanes < 10.5’	10
8	Rural	Shoulder > 4’	10.5’ ≤ Lanes < 11.5’	11
9	Rural	Shoulder > 4’	11.5 ≤ Lanes ≤ 12’	12
10	Urban	No Median/No CG	9.5’ ≤ Lanes < 10.5’	10
11	Urban	No Median/No CG	10.5’ ≤ Lanes < 11.5’	11
12	Urban	No Median/No CG	11.5 ≤ Lanes ≤ 12’	12
13	Urban	No Median/CG	9.5’ ≤ Lanes < 10.5’	10
14	Urban	No Median/CG	10.5’ ≤ Lanes < 11.5’	11
15	Urban	No Median/CG	11.5 ≤ Lanes ≤ 12’	12
16	Urban	Divided/No CG	9.5’ ≤ Lanes < 10.5’	10
17	Urban	Divided/No CG	10.5’ ≤ Lanes < 11.5’	11
18	Urban	Divided/No CG	11.5 ≤ Lanes ≤ 12’	12
19	Urban	Divided/CG	9.5’ ≤ Lanes < 10.5’	10
20	Urban	Divided/CG	10.5’ ≤ Lanes < 11.5’	11
21	Urban	Divided/CG	11.5 ≤ Lanes ≤ 12’	12
22	Urban	Bituminous Median/No CG	9.5’ ≤ Lanes < 10.5’	10
23	Urban	Bituminous Median/No CG	10.5’ ≤ Lanes < 11.5’	11
24	Urban	Bituminous Median/No CG	11.5 ≤ Lanes ≤ 12’	12
25	Urban	Bituminous Median/CG	9.5’ ≤ Lanes < 10.5’	10
26	Urban	Bituminous Median/CG	10.5’ ≤ Lanes < 11.5’	11
27	Urban	Bituminous Median/CG	11.5 ≤ Lanes ≤ 12’	12
28	Urban	TWLTL/No CG	9.5’ ≤ Lanes < 10.5’	10
29	Urban	TWLTL/No CG	10.5’ ≤ Lanes < 11.5’	11
30	Urban	TWLTL/No CG	11.5 ≤ Lanes ≤ 12’	12
31	Urban	TWLTL/CG	9.5’ ≤ Lanes < 10.5’	10
32	Urban	TWLTL/CG	10.5’ ≤ Lanes < 11.5’	11
33	Urban	TWLTL/CG	11.5 ≤ Lanes ≤ 12’	12

Table 3.2: Mileage Available within Initial Categories using RIMS Database Selection

	>0.1 mi Segments		>1/4 mi Segments		>1/2 mi Segments	
Category	**State**	**Selected Counties**	**State**	**Selected Counties**	**State**	**Selected Counties**
1	100	14	69	9	28	3
2	39	7	22	4	7	2
3	77	19	49	15	25	9
4	13870	2637	13600	2588	13010	2476
5	2991	690	2959	682	2887	665
6	1076	255	1051	251	1008	241
7	423	65	397	59	372	53
8	1823	326	1755	313	1612	287
9	3652	848	3597	834	3494	804
10	3299	1118	2720	970	1925	735
11	1104	376	933	326	703	251
12	1112	443	934	373	699	287
13	54	15	35	10	18	5
14	59	17	37	10	15	3
15	134	38	91	26	44	13
16	8	0	6	0	4	0
17	5	0	3	0	1	0
18	227	80	215	76	198	69
19	3	2	2	1	1	0
20	4	1	3	1	1	1
21	10	5	9	5	7	4
22/28	8	7	7	6	5	5
23/29	10	5	5	2	1	0
24/30	152	71	131	60	108	50
25/31	2	1	1	0	1	0
26/32	18	9	15	7	14	7
27/33	84	43	75	38	65	36
Grand Total (mi)	**30346**	**7093**	**28720**	**6666**	**26252**	**6005**

The last six rows in Table 3.2 are actually groups of two categories because the RIMS database does not provide a distinction between bituminous medians and TWLTLs. Therefore, the filtering of the database resulted in segments that could fall into either median category. The separation of segments with a bituminous median and segments with a TWLTL had to be performed manually. Table 3.2 reveals that the total mileage of roadway segments for the majority of urban categories was insufficient in producing the desired sample size of 30-40 segments per category. The research team then made the decision to simplify the categories based on the roadway classifications found in the HSM. These classifications include:

- 2U – Two-lane undivided roadways (Rural and Urban)
- 3T – Three-lane roadways with TWLTL (Urban)
- 4D – Four-lane divided roadways (Rural and Urban)

- 4U – Four-lane undivided roadways (Urban)
- 5T – Five-lane roadways with TWLTL (Urban)

3.3.2 Modifications to the Segment Selection Process

After reclassifying the segments, individual segments needed to be selected for verification in the field. The team began by making trips to the SCDOT Pickens County Office to make use of the Photolog Viewer available on-site. This tool enables the user to view SCDOT roadway maps and to access the attributes for a particular segment in the RIMS database by simply clicking on the individual segment. Additionally, the user can obtain the exact mile point at any location and access the recorded Photolog image anywhere along the segment by clicking on a point of interest. Using this interface, the team planned to identify roadway segments corresponding to each HSM roadway classification for field verification using Clemson University's MTSL. It quickly became apparent that logistical issues made it inefficient to use the Photolog Viewer at the SCDOT Pickens County Office. In addition, the team found that the reliability of this method with regard to accurately representing the roadway geometry in the field would not be sufficient for the purposes of this project. Knowing that the data collection and verification process would be an extensive one, the team needed to be confident that the routes driven using the MTSL would provide ample study sites for analysis that meet the requirements listed above. While the Photolog generally provided an accurate representation of each segment in the field, several problematic inconsistencies were found in the RIMS database, including:

- Individual segments had several geometric changes within the segment
- Some segments began/ended where no geometric change existed
- Segments passed through intersections without a break and thus no acknowledgement of a change in geometry
- No information on horizontal curvature
- No information on presence of auxiliary lanes
- No information on lane specific widths
- No information on transition zones
- No distinction between bituminous medians, turn lanes, and TWLTLs
- No indication of on-street parking
- Inaccurate or missing median widths
- Inaccurate or missing shoulder widths
- Locations with no Photolog image available

Due to the necessity of procuring a sample of segments with uniform geometry from start to end, the team decided to develop a new procedure for identifying potential analysis sites.

3.3.3 Final Segment Selection

Segment selection initially involved creating thematic maps of roadway segments in each of the chosen nine counties based on the estimated AADT in 2010 for each segment, which is provided in the RIMS database. This served as a visual aid to illustrate which routes carried the bulk of the traffic within each county. Routes with low traffic volumes were avoided to eliminate local roadways and other segments that behave similarly. Figure 3.2 below is an example of one of the thematic maps produced in ArcGIS for estimated AADT in 2010. The research team used shapefiles of existing US, State, and

Secondary roads obtained from the SCDOT GIS and Mapping website and linked them with the RIMS database through linear referencing [SCDOT, 2011]. Using Bing Maps Aerial Images, the AADT thematic maps could be created.

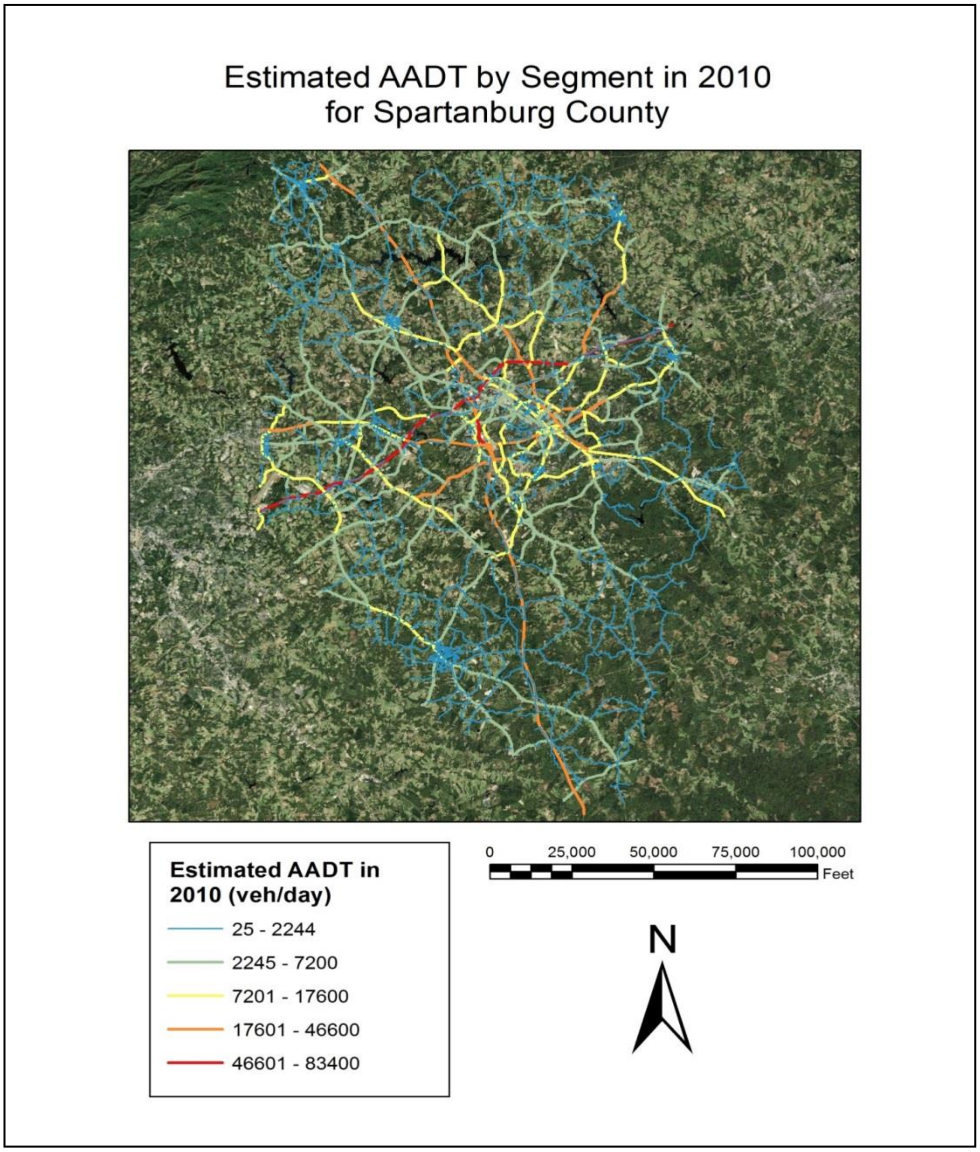

Figure 3.2: 2010 AADT Thematic Map for Spartanburg County

The team decided to use ArcGIS to sort each county's segments into five relative AADT groups. In general, AADT less than 2000 were sampled sparingly due to their abundance in the network. A research team member then used the maps to visually inspect each of the segments and assign proper HSM classifications. Figure 3.3 provides an example of a 2U segment verified using Bing Maps Aerials in ArcGIS.

Figure 3.3: Verifying a Two-Lane Undivided Road (2U) using Bing Maps Aerials

In locations where the aerial image was either blurry or unavailable at high resolutions, Google Earth and the Street View tool in Google Maps were used to verify the segments as well. An example of using Google Maps Street View to verify a 2U segment can be seen in Figure 3.4.

Figure 3.4: Verifying a Two-Lane Undivided Road (2U) using Google Street View

Only segments with geometrically uniform stretches of roadway longer than 0.1 mi were assigned an HSM classification. For segments where multiple sections of sufficient length corresponding to different HSM classifications were observed, the segment received more than one classification, such as “2U and 3T.” Once the final segments had been created, these segments were reexamined and given the proper classification. Complete summary statistics, including all final classifications for roadways within the sample, are available in Chapter 4. The research team then generated thematic maps, similar to those created to show AADT, to illustrate the distribution of segment types for each county. Figure 3.5 provides an example of this type of map for Spartanburg County. See Appendix A for the thematic maps of segment types for every other county.

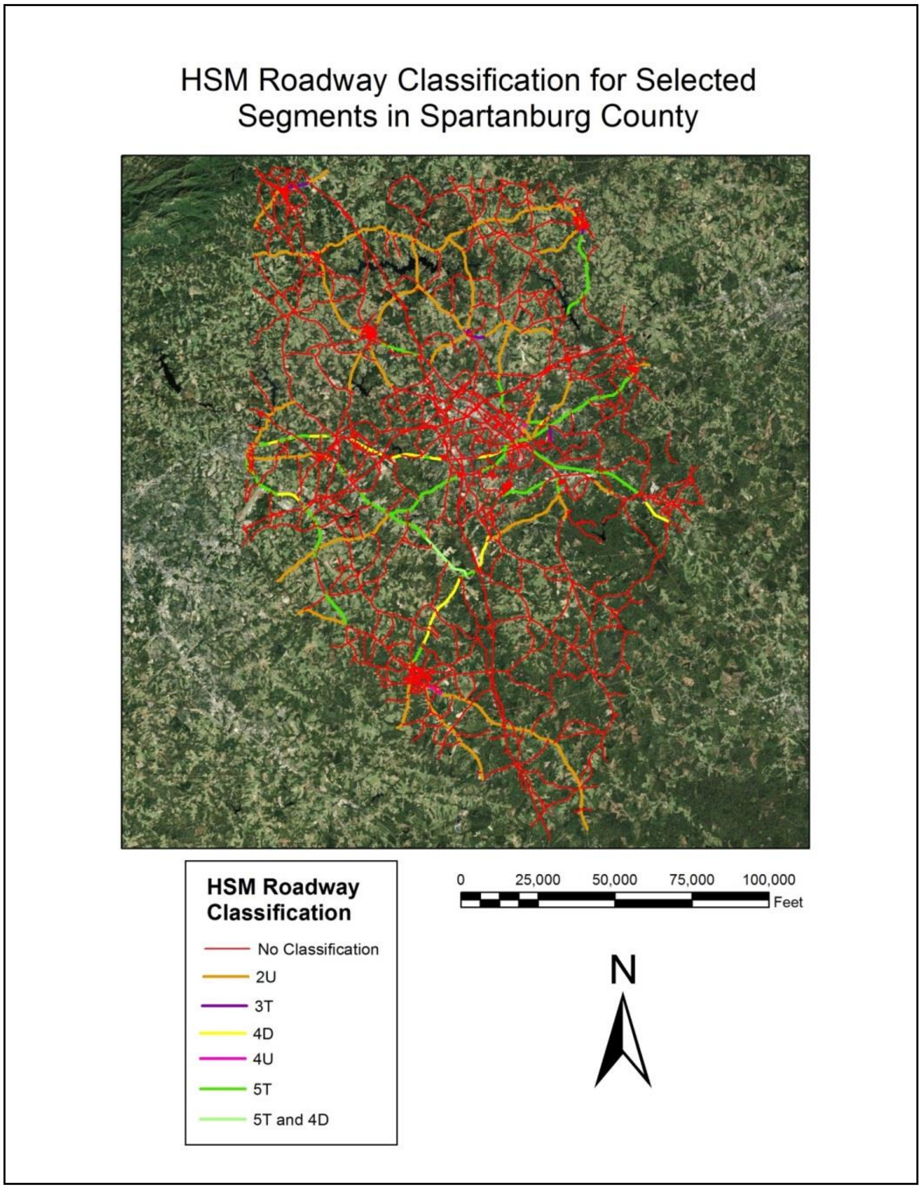

Figure 3.5: HSM Roadway Classifications for Segments in Spartanburg County

Once this process was completed for all nine counties, every segment that had been assigned an HSM classification required data collection in the field, and to do this, the project team needed to construct various routes to be driven in the MTSL.

3.4 Route Development and Data Collection

3.4.1 Initial Route Development

Once the team had identified the potential roadway segments for safety analysis, driving routes had to be developed so that field data could be collected for each segment using the MTSL. For two-lane roadways, driving the length of each segment in one direction was sufficient for collecting a thorough video log and laser rangefinder image inventory. This would allow for sufficient measurements of lane width, shoulder width, and clear zones. However, trial data collection runs revealed that due to the general range of the laser rangefinder, all segments with three or more lanes needed to be driven in both directions to ensure that all necessary measurements could be made. This posed a slight problem because most mobile GPS devices only allow the user to design a route for either the shortest distance or quickest time between two locations, possibly with a few detours. The routes needed for data collection required significant overlap and occasionally even the same starting and ending location. To do this, the team used the "Get Directions" tool in Google Maps. In particular, the ability to add "pins" to a route made this process work. By "pinning" a route, the route developer could create a path that had to pass through certain points in a particular order. The use of "pins" in Google Maps can be seen in Figure 3.6, which shows the route map for a portion of the first data collection trip in Pickens County. The "pins" are represented by small white circles along the route on the map, and they are listed in order directly above the turn-by-turn directions under the heading "Driving directions to US-123 S." The turn-by-turn directions seen in the bottom left corner of this image were printed for each data collection trip to assist the driver of the MTSL.

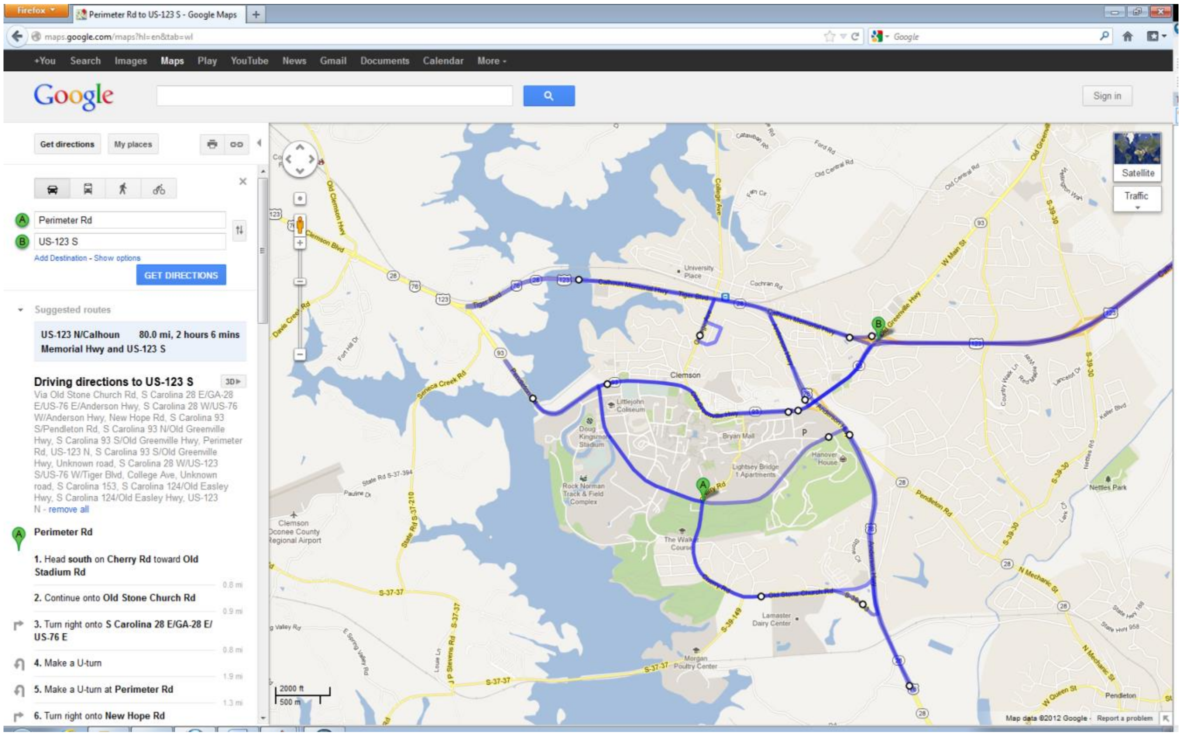

Figure 3.6: Using “Pins” in Google Maps to Design Routes in Pickens County

As a result, efficient routes could be created to traverse all the necessary segments as needed without having to make excessive detours along routes where data collection was unnecessary. The route developer also took certain logistical aspects of data collection into account. First, each data collection trip needed to encompass roughly 2-4 hours of driving. Shorter routes would have resulted in a considerable waste of time due the setup required prior to data collection. Longer trips also posed several problems because the van could not be turned off during data collection, so refueling needed to be done before or after each trip. Also, data collection could only be conducted during daylight hours because the video log is inoperable after sunset. In addition, the route developer considered the travel involved for each county and any necessary hotel accommodations. By strategically designing trips to start near the departure locations and end as close to the final destinations as possible, the route developer managed to save a considerable amount of time and money.

3.4.2 MTSL Setup and Data Collection

After developing a set of routes to adequately traverse all of the roadway segments selected by visual inspection, the team proceeded with the collection of all appropriate geometric data in the field. The main instrument used for this comprehensive data collection process was Clemson’s MTSL. The MTSL is a complete research vehicle, equipped with a front camera for video logging, differentially corrected GPS, and a rear-attached rotating laser capable of detecting road width information as well as grade, cross slope, and additional roadside features.

The use of video logging through a front camera allowed the project team to post-process more efficiently and discover additional attribute data from the segments. Also, the collected video logs provided a reference base for analyzing data obtained from the laser rangefinder in a particular location.

The availability of video at intersections proved critical as well to the saturation flow study and understanding lane configurations at a given intersection. The video logging program, V-Log, allowed the research team to collect video information from a front windshield camera and link it to the GPS and laser rangefinder data collected for the same time. Figure 3.7 below shows the positioning of the front windshield camera used for video logging.

Figure 3.7: Positioning of the Front Video Logging Camera in Clemson's MTSL

Satellite differential correction provides GPS points that are accurate to within one meter for any location in South Carolina. This allows the additional data collected from the video and the laser rangefinder to be spatially accurate. Figure 3.8 shows the three types of data collected simultaneously by the MTSL.

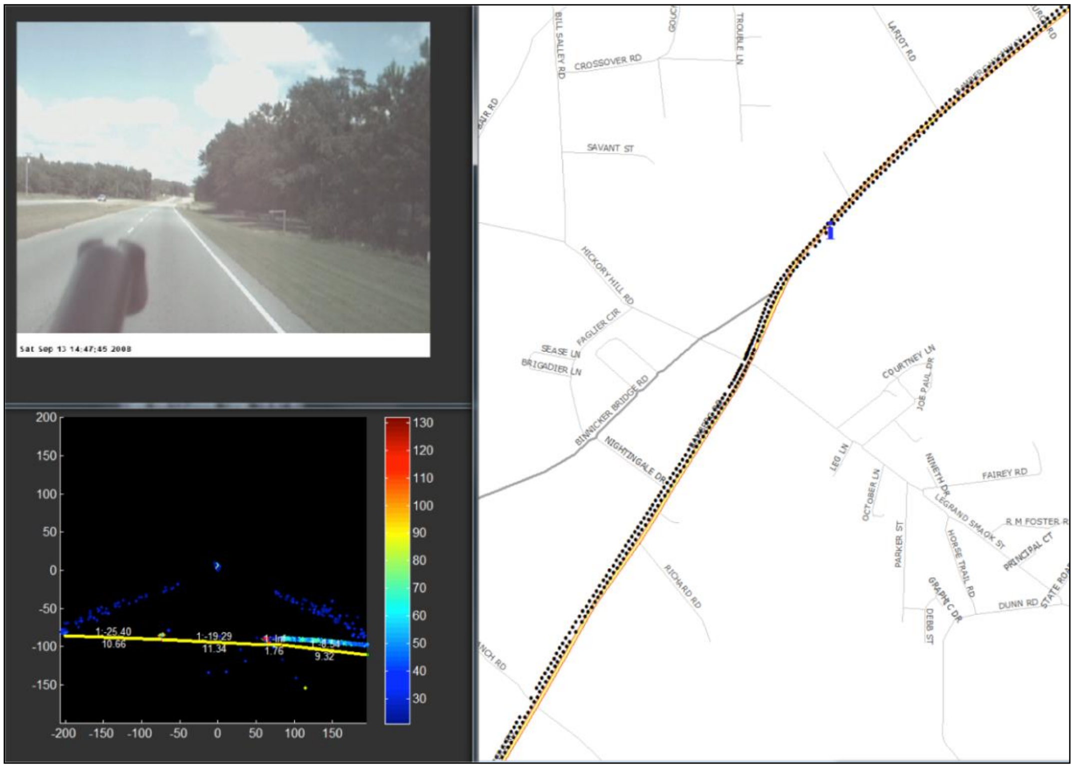

Figure 3.8: Post-Processing Laser Data using MATLAB

Maptitude was the primary program used to collect GPS information in real-time. A horizontal dilution of precision (HDOP) of 3.0 or less was deemed acceptable to ensure spatial accuracy. Ultimately, the GPS information collected in Maptitude was converted into a point shapefile to be used in ArcGIS along with the roadway segments obtained from the SCDOT GIS and Mapping website [SCDOT, 2011].

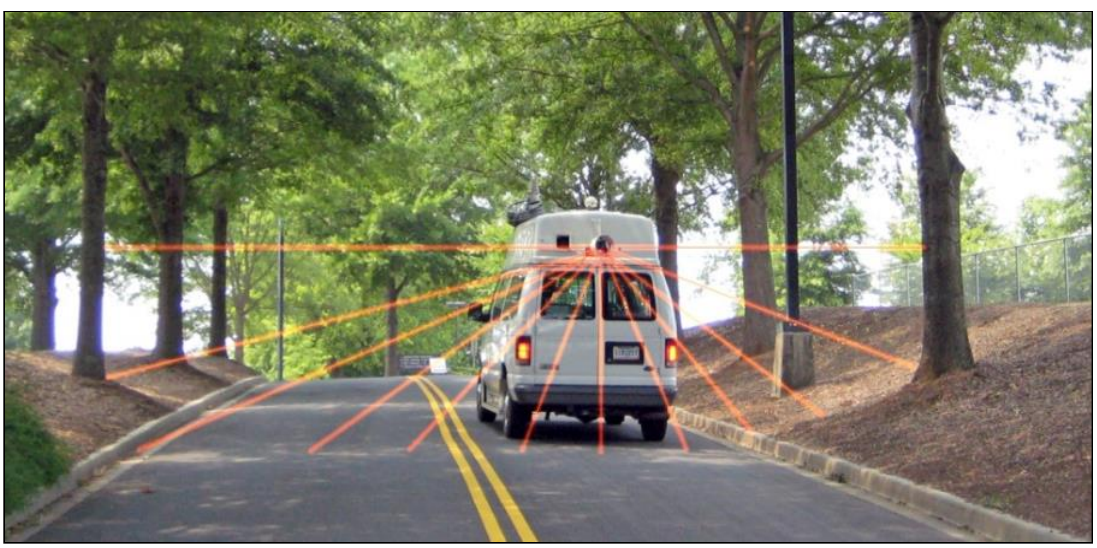

Figure 3.9: Using Clemson's MTSL to Measure a Roadway Profile

The Acuity AR4000 Laser Rangefinder and Line Scanner**,** shown in Figure 3.9 above, was the instrument used for precision width measurement on the selected roadway segments. This precise spinning mirror assembly creates a 360° laser scanner that is capable of measuring a complete profile of the roadway at a given time.

As previously discussed, some of the roadway attributes needed to conduct the cross-sectional analysis were provided by SCDOT in the RIMS database and applied directly to the selected segments. However, the use of rotating laser data proved critical to precisely measure lane and shoulder widths on selected roadway segments throughout the state. The research team wanted to achieve a high level of precision that would allow for observing the effect of incremental changes in lane width on the safety and operations of the roadway segments with confidence. For each trip, the research team chose a location to make calibration measurements of the roadway using a measuring wheel. These measurements were compared with the data collected by the laser rangefinder to ensure the accuracy of the laser rangefinder itself. Summary statistics for these calibration point measurements can be found in Chapter 4.

3.4.3 Driving Considerations for Data Collection

As mentioned earlier, trial data collection runs revealed that all roadway segments with more than two lanes had to be driven in two directions using the MTSL to ensure that sufficient data was collected for lane and shoulder widths on each segment. To maximize the usable data collected for each roadway segment, the research team also made an effort to drive along multilane segments in the left-most lane because the range and quality of the data collected to the right of the laser rangefinder's position was typically clearer than the data collected on the left side. The trial runs also provided feedback regarding the inability of the laser rangefinder to collect TWLTL width from the left-most travel lane. Figures 3.10 and 3.11 below show an example of data collected by the laser rangefinder for a 5T segment with the vehicle traveling in the left-most lane. In both figures, the position of the laser rangefinder is indicated by the small blue "V" located above the level of the roadway. In Figure 3.10, the white dashed lines on the right side of the roadway appear in warm colors, indicating a higher amplitude, and the TWLTL pavement markings nearest to the MTSL and the laser rangefinder register a slightly lower amplitude. Figure 3.11 shows that no other pavement markings on the left side of the roadway register with the laser rangefinder.

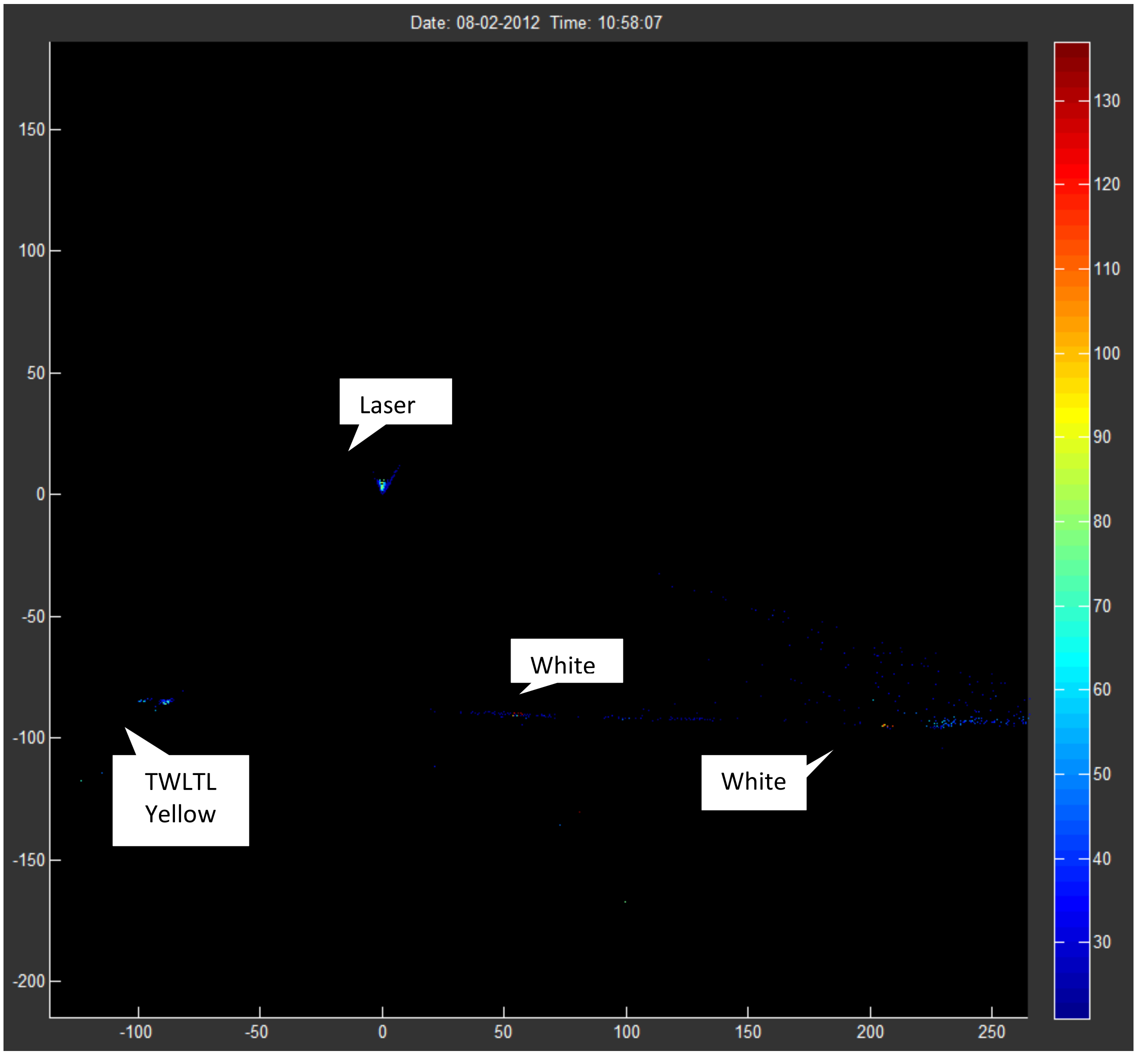

Figure 3.10: Collecting Data from the Left-Most Travel Lane on a 5T Segment, Part 1

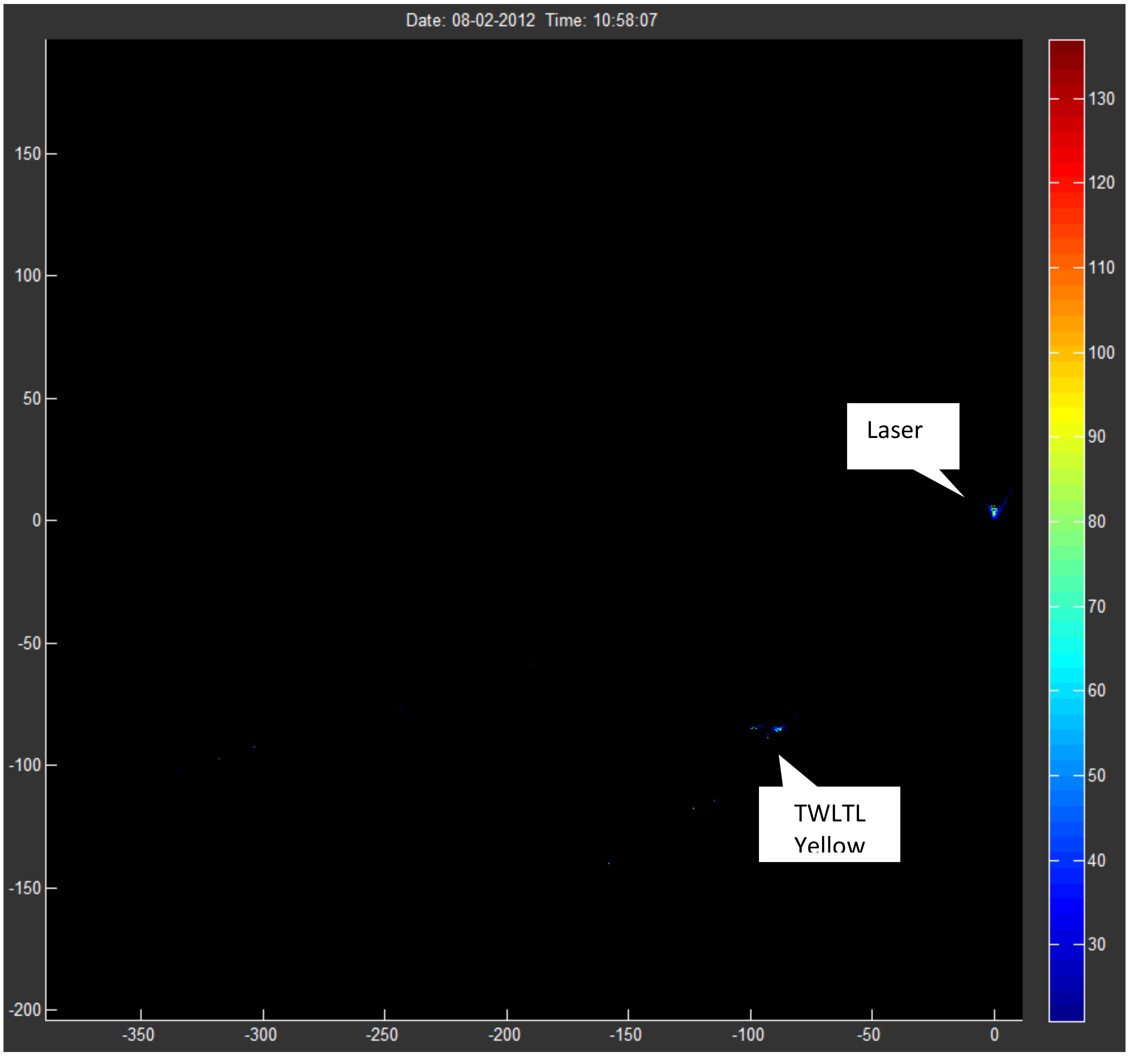

Figure 3.11: Collecting Data from the Left-Most Travel Lane on a 5T Segment, Part 2

Theoretically, there should be little difference between the range required to pick up the opposite side of a TWLTL and the range needed to pick up the opposite side of the pavement on a 2U segment, but the color of the paint lines makes a difference. White pavement markings typically generate a higher amplitude (range of 100-120) for the laser rangefinder to measure than yellow pavement markings (range of 50-70), making 2U segments easy to measure while driving in the opposing travel lane. Figure 3.12 below provides a typical image produced by the laser rangefinder for a 2U segment where all pavement markings are clearly visible. While the amplitude of the white pavement marking on the left side of the road is lower than that of the white pavement marking on the right side, it is still higher than the amplitude of the yellow centerline pavement markings and is easily picked up by the laser rangefinder.

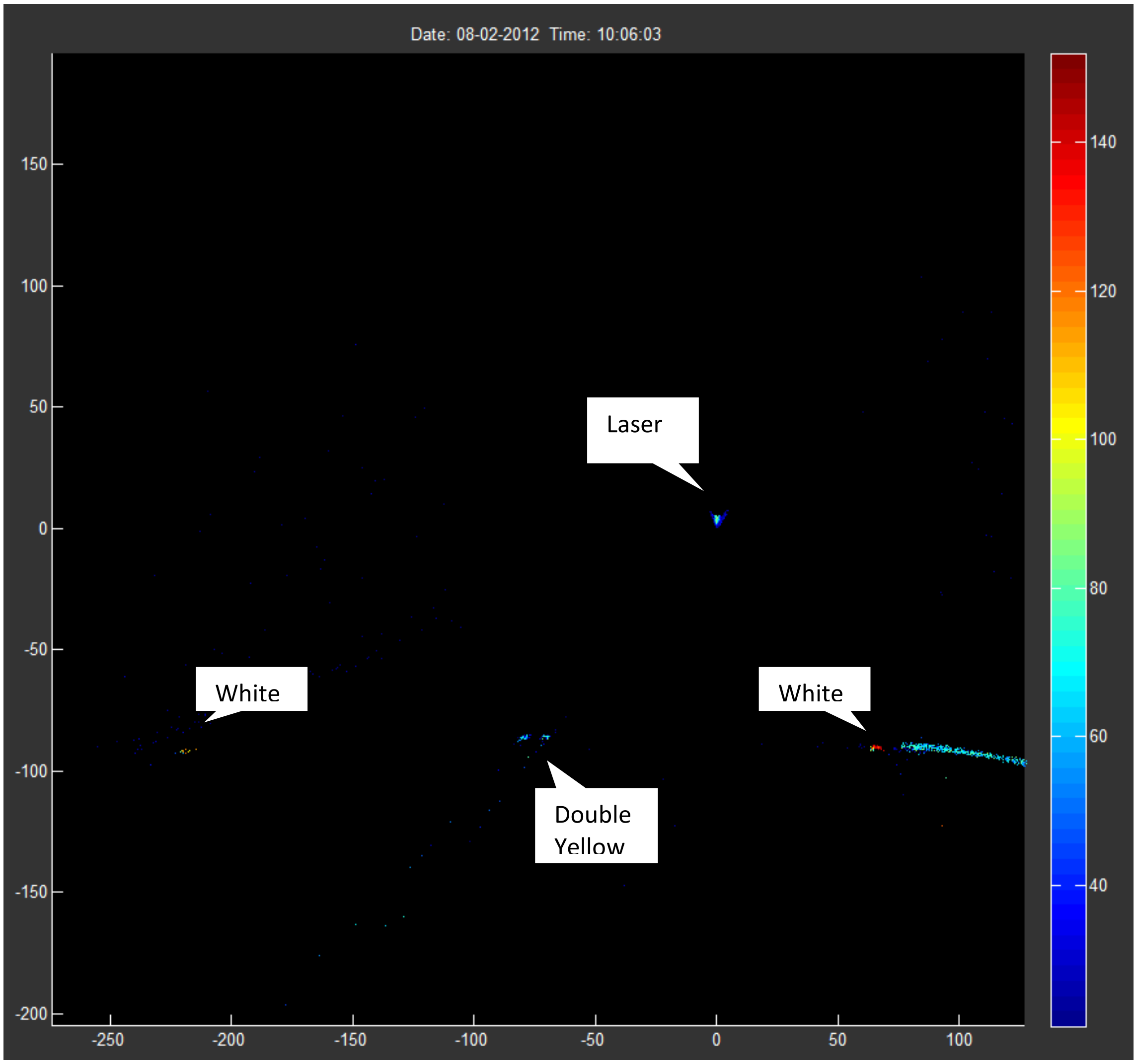

Figure 3.12: Collecting Data using the Laser Rangefinder on a 2U Segment

Since yellow pavement markings at approximately the same distance away from the laser rangefinder cannot be deciphered while driving in the left-most travel lane of a roadway segment with a TWLTL, the driver of the MTSL was therefore responsible for steering the vehicle into and out of TWLTLs on selected segments in a safe manner so that this data could be collected. At least two research team members attended each data collection trip in the MTSL: one to drive; and one to monitor the data collection equipment in the van, troubleshoots all technical difficulties that arose, and assist the driver with navigation when necessary. The research team attempted to drive at slower speeds when possible because it allowed for greater accuracy of GPS, video log, and laser rangefinder data collection. Since the GPS unit only collected information once per second, slower driving allowed for the collection of more data points in closer proximity to each other. Collecting more points per trip on a given roadway segment allowed the team to create detailed road profiles and collect all the desired pavement width information along a given segment.

3.4.4 Preparation for Data Collection

The team developed a general process before data collection began, including start-up procedures for computers and programs associated with the laser, GPS, and video collection process, as well as the proper mounting of the laser rangefinder and rotating mirror attachment to the rear of the MTSL. Concerning the video camera, it was important to run the video logging program, V-Log, prior to data collection. After checking that the position of the video camera was acceptable, team members could confirm that the program was collecting accurate, real-time video data. Additionally, the laser rangefinder data collection system was prepared by ensuring that data was mapping to the correct drive of the desktop computer, and the laser rangefinder's rotation speed was also checked. The research team prepared the GPS unit by checking for acceptable satellite coverage and confirming that GPS point data could be seen in Maptitude in real-time. In addition, because the data collected from the laser rangefinder, video log, and GPS must all be linked together based on time, the team ensured that times displayed by the internal clocks for both computers in the MTSL were synchronized with the GPS unit. Maptitude enabled the display of the time recorded by the GPS unit on the laptop. Throughout a given day of data collection, the research team periodically checked for time synchronization between the desktop receiving data from the laser rangefinder and the laptop receiving GPS and video log data. This was done to ensure accuracy when linking all three forms of data by time.

3.4.5 Field Data Collection

Several forms were created for field data collection to assist with coordination between the laser, video, and GPS information associated with a specific segment. In addition to the data collected directly from the MTSL, the project team collected additional geometric information by hand at selected points to ensure calibration of the laser data.

3.4.6 Saturation Flow Data Collection Process

A saturation flow study was developed to observe the operational effect of lane widths at various signalized intersections in South Carolina. Thus, throughout the driving process, the team stopped to collect lane width measurements and saturation flow rates of specific through and turning movements along the designed routes. The team did not attempt to determine which intersections would be suitable for saturation flow analysis prior to data collection, particularly because the team members lacked familiarity with many of the areas, and it was difficult to gauge time and traffic during data collection. Instead, judgment was used to determine when and if a given intersection would be suitable based on observations both during and after data collection. Once the intersections had been selected for saturation flow analysis, detailed measurements were made for all shoulders, lanes, medians, and buffers for each intersection approach using a measuring wheel.

The measurement of saturation flow required a queue of at least five vehicles in a given lane during the red phase for that particular movement. The first two vehicles in the queue were ignored to eliminate the influence of start-up acceleration at the beginning of the green phase. Stopwatches were used to measure the total time elapsed between the third vehicle entering the intersection and the final vehicle in queue entering the intersection. Measurement stopped once the queue had dissipated. Using the total number of vehicles passing through the intersection during this time, the saturation flow headway could be calculated for each measurement. Three measurements were taken per lane whenever the saturation for a given lane was sufficient to accomplish this at the time of data collection.

For the purposes of this study, queues with heavy vehicles were excluded to prevent any skewing of the data due to the larger lengths and slower accelerations of these vehicles. Exceptions were made for queues with heavy vehicles where at least five vehicles preceded the first heavy vehicle. In these cases, the measurement was stopped at the time when the vehicle directly in front of the first heavy vehicle entered the intersection.

3.5 Processing Segment Data

3.5.1 Initial Measurements on Selected Segments

Once the data collection process had been completed, all of the data accumulated using the MTSL had to be processed. The first processing step was to export the GPS data as point shapefiles so that they could be used in ArcGIS along with the roadway segment shapefiles containing the attributes pulled from the RIMS database. Next, MATLAB Software was used with a Laser Graphical User Interface (GUI), shown below in Figure 3.13. The Laser GUI software was developed within the Department of Civil Engineering for a previous project conducted for SCDOT by Clemson University on clear zones.

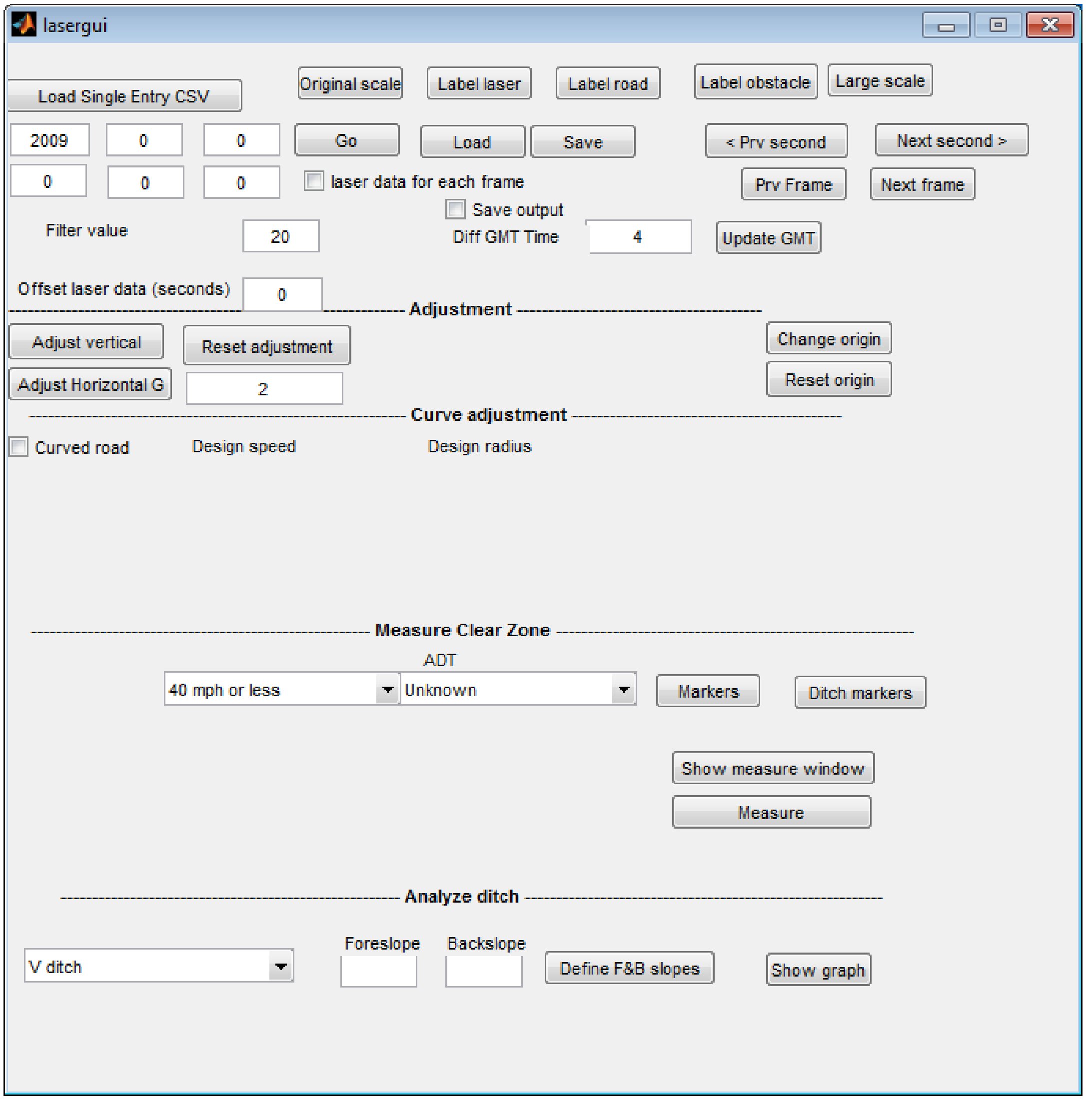

Figure 3.13: Laser GUI Developed in MATLAB

This interface enables the user to access an image created by the laser rangefinder, along with the corresponding image from the video log, by entering a specific date and time of interest. The team then used the “Markers” tool, originally designed to measure clear zones, to measure lane and shoulder widths at various locations on the selected segments. To guarantee the investigation of all potential analysis sites, research team members followed the GPS points in chronological order for each data collection trip. By using the thematic maps created during segment selection, Bing Maps Aerials, and intersection buffers developed in ArcGIS, the team members identified and made measurements at ideal locations. The Laser GUI provides a connection between a specific point in time and the corresponding image produced by the laser rangefinder during that time.

The introduction of intersection buffers improved the efficiency of identifying points for measurement. As mentioned earlier, the team desired to exclude the influence of intersections in this study as much as possible. According to Chapter 14 of the HSM, many agencies consider an incident that occurs within 250 ft of the center of an intersection to be an intersection-related crash, although this is not necessarily the case in all circumstances because a crash occurring with 250 ft of an intersection may have occurred regardless of the presence of the intersection [AASHTO, 2010]. For the purpose of this study, it was determined that this 250 ft value would be acceptable because the risk of using segments that would skew crash data far outweighed the possible negative effect of ending up with fewer or shorter segments.

Since a shapefile for point locations of intersections within the sample was not readily available, the team designed a model in ArcGIS to locate all intersections along the sample segments. This model identified intersections between the selected segments and all US, State, Secondary, and local roads. Several of the segments in the roadway networks did not quite intersect even though the aerial images clearly showed that they should. Therefore, a snap tolerance was developed using GIS topology rules to ensure that all intersection nodes could be located and extracted. The team then generated the 250 ft intersection buffers using a buffer tool. Using both the intersection buffers and aerial images provided in ArcGIS, the team identified ideal measurement locations along selected routes. Additionally, the research team decided to make all appropriate measurements, regardless of the location of intersection buffers for 3T, 4U, and 5T segments, as long as sufficient stretches of uniform geometry could be found. Since these segments are typically located in urban areas with greater intersection density, eliminating all influence of intersections on the incidents occurring along these roadway segments would have greatly reduced the amount of suitable segments.

3.5.2 Creation of New Segments

As discussed earlier, the existing segments obtained from the SCDOT GIS and Mapping website and RIMS overlay [SCDOT, 2011] did not correlate well to the desired analysis sites for this project. As a result, a new database of segments was created with entirely different starting and ending locations from the original RIMS segments. In developing an entirely new sample of homogeneous segments, several factors had to be considered. First, the new starting and ending locations of segments depended on the measurements made by the research team. To accommodate for this, measurements were assigned to a specific GPS point rather than the existing RIMS segment. Each measurement was then classified as either a “Good” measurement or a “Bad” one, corresponding to the uniformity of the lane width measurements. The general nature of pavement markings and the inherent error involved in the measurement procedure outlined above meant that some allowance had to be made for some disparity between the measurements of different lanes on the same segment. However, information on the lane responsible for individual crashes is not readily available, and this project was designed to investigate how different lane widths correlate to crash frequency. Using a two-lane roadway segment with an average lane width of 11 ft is not appropriate if one lane is 10 ft wide and the other 12 ft wide. As indicated in the literature review, drivers tend to react to pavement markings rather than the actual available pavement width [Godley et al, 2004]. The research team ultimately decided that a difference of 0.5 ft or less would be acceptable at a given point and classified these as “Good” measurements. Any measurement where lanes differed by more than this was considered a “Bad” measurement. The research team then manually selected new starting and ending points for each segment that contained a consistent length of “Good” measurements.

The decision on whether or not to use a particular portion of a segment in the analysis differed greatly depending on the segment type. The two most common types of roadway segments in South Carolina are 2U and 4D segments. This wide availability allowed the analyst to create new segments of these types solely along stretches of roadway at least 250 ft away from the nearest intersection, with uniform geometry, and without significant horizontal curvature. Curve sections were identified as such to enable analysis with and without curve sections on 2U segments. Additionally, new 2U and 4D segments were only created if the entire section of roadway had only “Good” measurements and the difference between the smallest lane width and largest lane width measured less than 0.5 ft. Figure 3.14 depicts a 2U segment where a new segment was created while Figure 3.15 highlights a section of a 2U segment deemed unsuitable for analysis due to the presence of horizontal curvature and “Bad” measurements. In these images, the green points represent “Good” measurements, and the red points indicate “Bad” measurements. In many instances, the ‘Bad” measurements stemmed from unbalanced lanes, where when striped the lane width on one side was significantly larger than the other side. Because the striping is assumed to affect driving behavior, these sites could not be used.

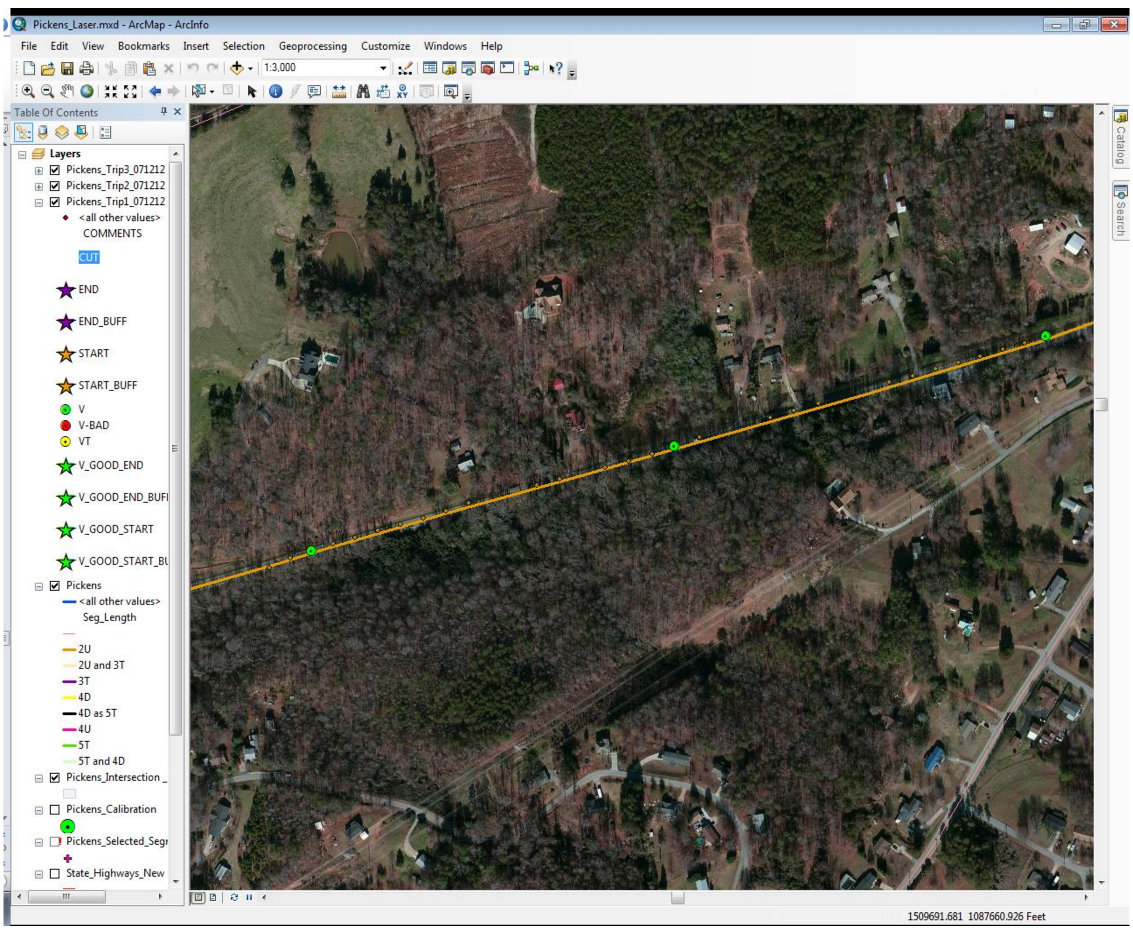

Figure 3.14: Identifying “Good” Measurements on a 2U Segment

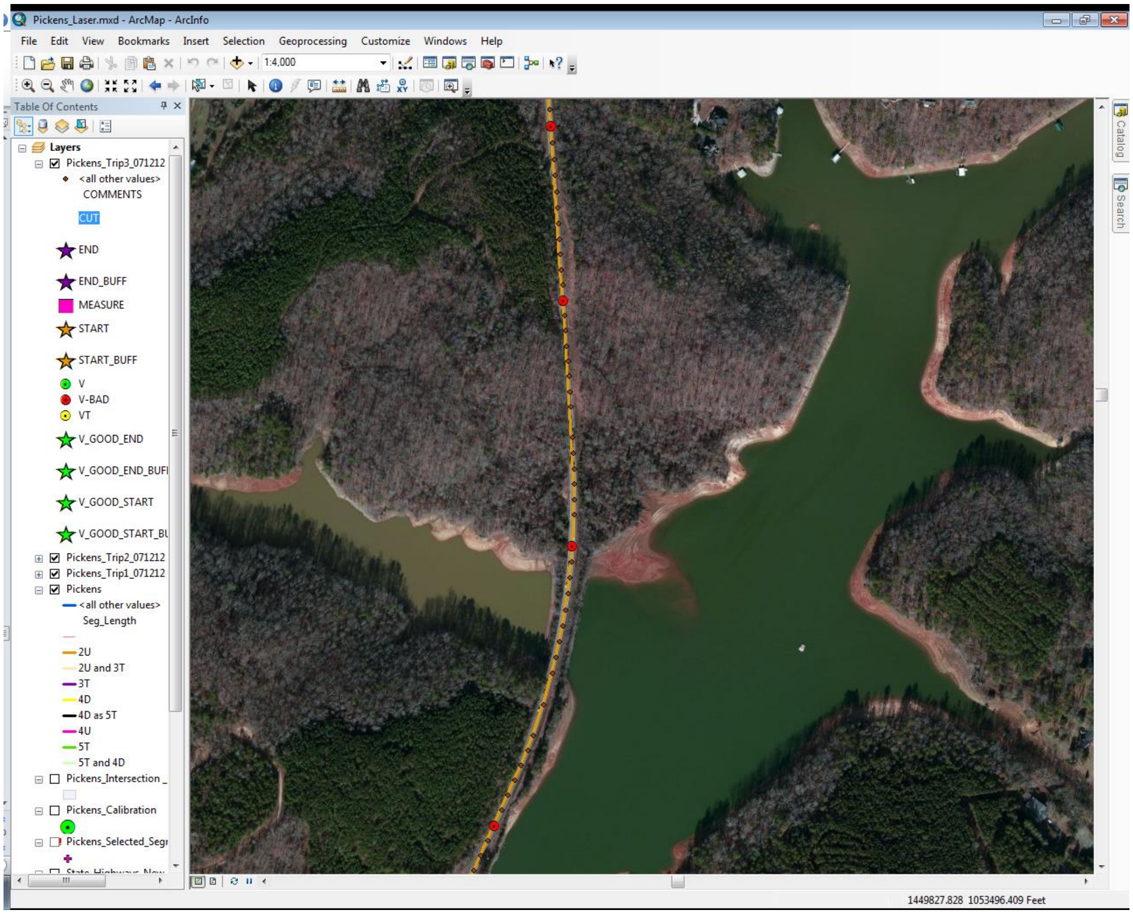

Figure 3.15: Identifying Curves and "Bad" Measurements on a 2U Segment

Due to the relative scarcity of 3T, 4U, and 5T segments in South Carolina, as well as the typical urban nature of these types of segments, the team did not factor into "Bad" measurements, horizontal curvature of the roadway, or the presence of intersection buffers when determining the starting and ending locations of these segments. However, the priority certainly was to collect straight sections longer than 0.1 mi with no intersections. While "Bad" measurements inhibit the ability to develop accurate models describing the relationship between lane width and crash frequency, segments were still created on many of these segments. The project team considered this appropriate because the correlation of other factors, such as TWLTL width and the presence of uniform curb and gutter, could still be analyzed on these segments. Figure 3.16 is an example of a 5T segment where a new segment was created despite the presence of an intersection and two "Bad" measurements. The segment exhibits uniform geometry in excess of 0.1 mi, and the intersection present on the segment is small and does not alter this geometry. The yellow point in this image represents a TWLTL measurement, and the larger teal circle represents the 250 ft buffer considered for all intersections.

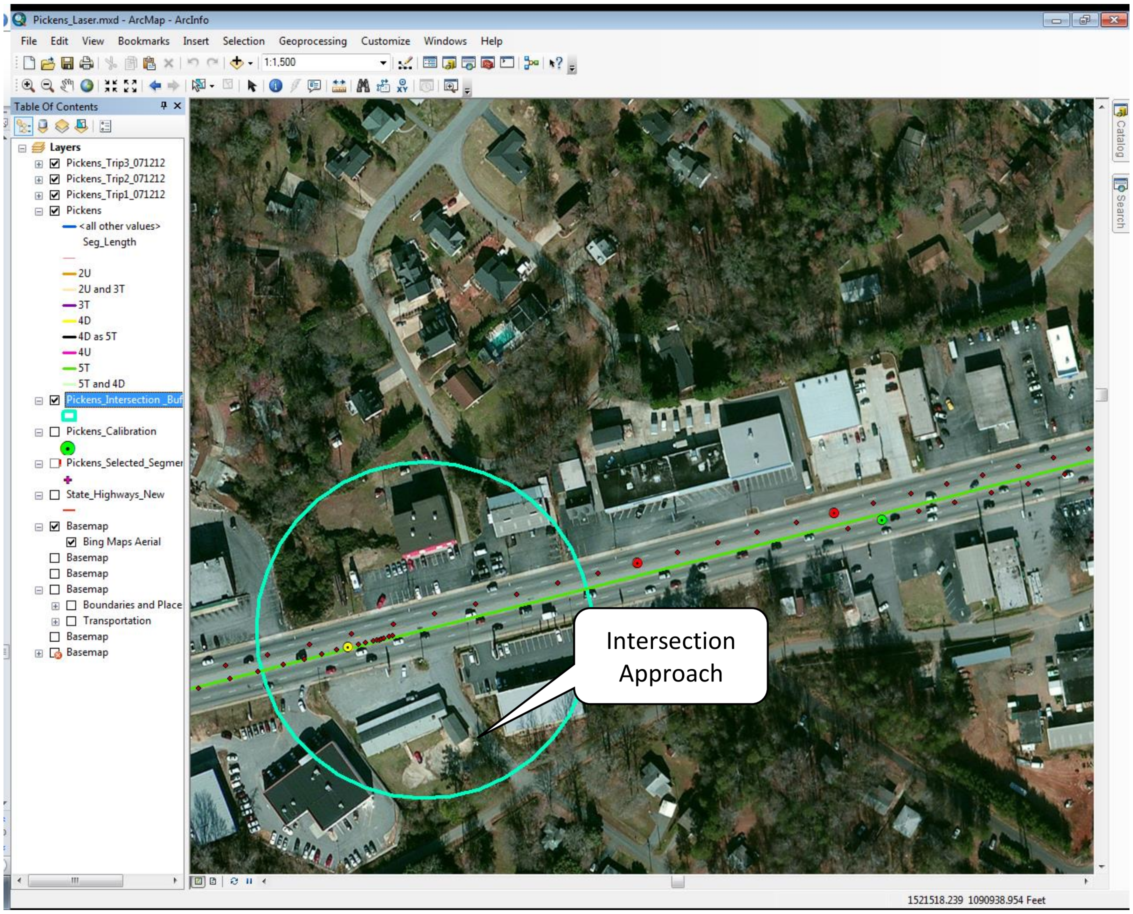

Figure 3.16: Creating a 5T Segment despite the Presence of an Intersection

Once the team completed the selection of starting and ending points for all new segments, another model was developed in ArcGIS to define segments with new starting and ending points from the existing RIMS road network. The model also allowed the attributed information from the RIMS database to be carried over to the new segments, along with other data collected in the field. By using the desired starting and ending points for new segments, which were linked to the existing GPS points, the team could cut and snap the existing segments to new points. Some of the new starting and ending points were designated at the edge of intersection buffer zones, and some were simply designated where geometry would change. The team was able to use the intersection buffers on 2U and 4D segments to remove all portions of the existing RIMS segments within 250 ft of an intersection. To delete other portions of the existing RIMS network that were considered unusable, various “Cut” points were added manually for the model to run properly.

3.5.3 Attributing Other Data to New Segments

Once the new segments had been created and lane width measurements were made, certain data still remained to be collected and attributed to each of the new segments. The literature review outlines some of the many factors listed in the HSM that influence safety on rural roadways. For the purposes of this study, the team decided to collect the following properties from the field:

- Number of Driveways
- Presence or Absence of Roadway Lighting
- Speed Limit
- Grade

Additionally, the presence of curb and gutter was added to this list, although it is not one of the safety factors discussed in the HSM. The research team collected these attributes after the development of the new segments to reduce the already extensive workload. Two team members used the Bing Maps Aerials to identify driveways and the video log to identify the speed limit and presence of lighting for each new segment. The video log image in Figure 3.17 demonstrates the use of a caption to make note of the speed limit observed in the field. These field notes made the process of finding speed limits for each new segment much easier. Although the team did not find many new segments containing stretches with multiple speed limits, the predominant speed limit was chosen in these circumstances.

Figure 3.17: Identifying Speed Limit on a 4D Segment

Although driveway type is listed by the HSM in addition to the number of driveways, it was not considered for urban segments because it was difficult to find an effective and efficient method for distinguishing between the various types of driveways outlined in Chapter 12 of the HSM [AASHTO, 2010]. After obtaining a complete sample of roadways with the desired attributes for analysis, the team needed to assign crashes to these new segments before commencing with the cross-sectional analysis. The crash geocoding process is described in the following section.

3.6 Processing Crash Data

3.6.1 Geocoding and Assigning Cash Records

The Clemson research team geocoded three years (2007-2009) of crash data for safety analysis. Consistent with the segment selection process, the selection of records was limited to US, State, and Secondary routes only within the selected counties described earlier. In addition, to ensure that crashes less likely to be affected by lane width were excluded, the selection was limited to the following types of crashes:

1. Head-on collisions;
2. Sideswipe events (both opposite direction and same direction); and
3. Run-off-the-road events leading to median crossovers, rollover events, and fixed object collisions.

In the analysis of 5T crashes, angle crashes were added in as well to account for crashes related to the turn lane itself.

Because all enforcement agencies in South Carolina currently use GPS coordinates for reporting crashes, the accuracy of crash reports is becoming increasingly critical for the development of beneficial safety studies. For the geocoding process to work properly, the crash data obtained from SCDOT had to be reformatted using conditional queries in Microsoft Access. This allowed for proper importing of the crash data into Maptitude. Maptitude's attempts to geocode the crash locations revealed several problems with the provided data, many of which have been identified as erroneous by Sarasua et al. [2008] using SCDOT safety data from as far back as 2004. The provided crash database contained 29,991 potential lane-width related crashes, 4,313 of which did not have complete coordinate information. Of the 4,313 records that lacked complete coordinate information, 2,261 entries were successfully geocoded using street names. Many of the crash record latitude and longitude values were located outside of the county in which the crash was designated or even outside of South Carolina. With this in mind, the project team corrected several of the commonly occurring systematic errors present within the provided records:

1. Some coordinates were recorded in decimal degrees rather than degrees-minutes-seconds;
2. Some coordinates were recorded with insufficient precision to geocode crashes accurately;
3. Some coordinates had longitude and latitude transposed;
4. Most of the longitude values did not include a negative sign;
5. Several crash records were missing latitude, longitude, or both;
6. Many crash records had erroneous coordinate values; and

7. Some coordinates were not in longitude and latitude format but rather in state plane coordinates (South Carolina NAD 83, with units in feet).

These common problems were noted previously in a paper published by Sarasua et al. [2008]. It is worth noting that the magnitude of these problems had increased since the original publication in 2008.

3.6.2 Using Commands and Querying Crash Records in Access

Operating and manipulating different types of commands and queries in Access became critical to successfully filtering and geocoding the provided crash data. For example, to successfully identify which coordinates were incorrectly assumed to be in degrees-minutes-seconds, the team had to become competent in manipulating strings in Access. Using typical commands such as "Mid," one can extract a substring from a larger string, beginning at any position. Figure 3.18 below shows a few records in the original crash database.

STR_LAT_8	STR_LAT_DEG	STR_LAT_MIN	STR_LAT_SEC
34300860	34	30	0860
34294680	34	29	4680
34325980	34	32	5980
34010098	34	01	0098
33170220	33	17	0220
33370040	33	37	0040
33232892	33	23	2892
34295830	34	29	5830
34323610	34	32	3610
34311480	34	31	1480
34320160	34	32	0160

Figure 3.18: Using Access to Manipulate Strings and Eliminate Crash Records

This particular record could be broken into its components of 34º1'0.98''. Once the 8-digit latitude coordinate was broken into its string components, they could be converted to numbers using the "Val" command. It was important to identify if any minute or second values were greater than 60 because those particular values were most likely falsely recorded in decimal degrees. Manipulating strings proved helpful for identifying records with more than two trailing zeroes. Eliminating these records was important because they lack the previously mentioned minimum precision of 1 second and can easily skew a set of data.

Beyond the use of string and number commands, queries were incredibly important to the geocoding process in Access and Maptitude. For example, the provided crash database was organized with entries in several tables. These tables separate attributes of a particular crash event by location, unit, and occupant information. Complete attribute lists associated with these tables are available in the South Carolina Traffic Collision Report Form (TR-310) and Supplemental Bus and Truck Report Form

Instruction Manual [2001]. Almost all of the desired crash attributes associated with this project were available in the location table, but the team wanted to link the attributes describing the "Manner of Collision" and "Most Harmful Event" from the unit table back to the overall sample table. This was completed using queries in Access. Figure 3.19 below shows a "Select" query in Access.

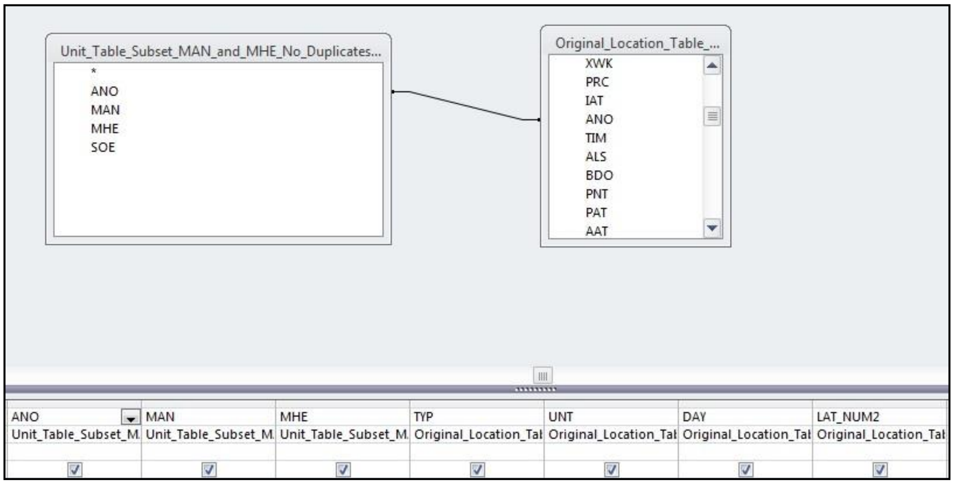

Figure 3.19: Using Queries in Access to Link Tables with Unique ID Numbers

By linking the location records to the unit records using a unique accident number (ANO), attributes can be shared across multiple tables. Once all the desired information regarding the crash records was obtained in one cohesive table, the records could then be exported to Maptitude for geocoding.

3.6.3 Using Maptitude in Coordination with Access to Update Records

As described above, crash records were separated into two principal groups for geocoding: regular records, which were to be located with coordinate information; and leftover records, which were to be located with street and intersection information, if available. The regular records were queried in Access to include all crashes with enough precision and no missing latitude or longitude values. Any corrected transposed records were also included in this group. The final coordinate values for geocoding had to be converted to numbers in decimal degrees for Maptitude to properly recognize. Figure 3.20 below shows how erroneous crash coordinate data was identified and eliminated in Orangeburg County.

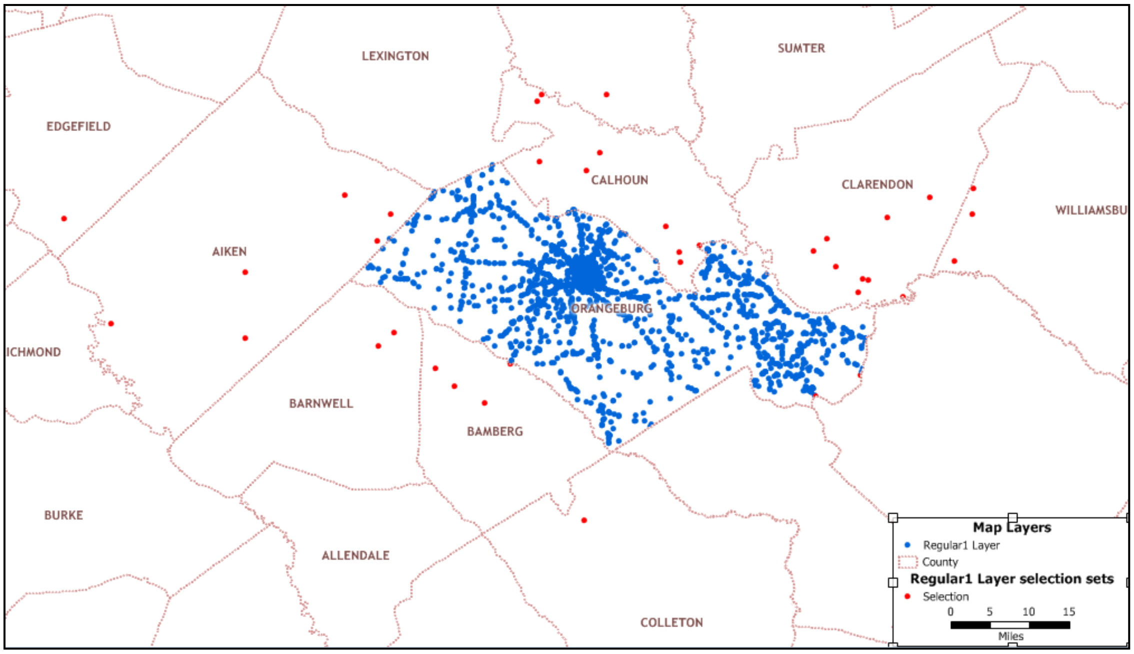

Figure 3.20: Eliminating Crash Records with Erroneous Coordinate Data

For each county in the sample, the regular records were geocoded using latitude and longitude coordinates. Crash records that were revealed to be outside the border of a desired county were then selected in GIS and grouped back into the sample of leftovers. It was important not to fully eliminate any crash records until they had been properly geocoded using coordinate information, if possible, and street information.

Records that had failed to be geocoded using coordinate information were appended to the leftovers group in Access using queries, and then the geocoding process could continue. Because many of the crash records in the leftovers group contained fields for “Collision Street Name,” “Base Street Name,” and “Second Street Name,” Maptitude is capable of geocoding points using the nearest intersection of these streets.

Records that were unable to be geocoded with coordinate information or street information were considered unusable. After all records for a particular county had been analyzed, a sample of accurate crash occurrences could be developed. Figure 3.21 below shows the final set of geocoded crash records in Orangeburg County.

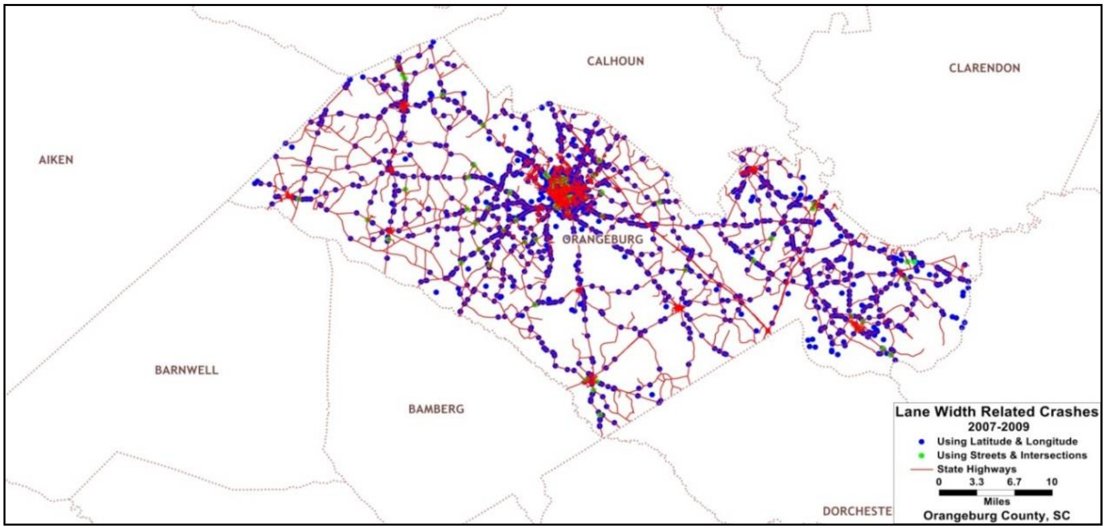

Figure 3.21: Geocoded Crash Records in Orangeburg County

The project team was able to successfully geocode crashes using this process for all nine counties within the sample. The use of Access and Maptitude in conjunction proved critical to the development of accurate crash records. With this process completed, these crash records could be attributed to specific roadway segments within the sample.

The team developed a model to spatially join overall crashes within a 65 ft distance perpendicular to the centerline of each segment. A join was performed for each crash type as well as the total crash sum on the newly created segments. With all of the geometric and incident related properties for each of the newly created segments gathered, a cross-sectional analysis could be developed to determine the correlation between roadway safety, lane and shoulder width.

3.7 Model Development

Following the data collection and post-processing of geometric, traffic, and crash data, numerous cross-sectional crash prediction models were created to assess the highways within the inventory of newly created roadway segments. The research team used the variables collected for these segments in conjunction with the crash history obtained from SCDOT. Ultimately, the goal of the model was to determine the correlation of various roadway characteristics to the frequency of crashes for each roadway type outlined in the HSM. Since the variables collected for rural highways differed from the urban and suburban facilities, different models were created to analyze those segment types separately.

3.7.1 Aggregation of Sample Segments

Before running the model, the samples were aggregated to reduce possible bias caused by flooding any pool of data with too many segments from the same route and with the same attributes. Summary statistics for the original sample and the corresponding aggregated segments can be found in Chapter 4. Using Microsoft Access, the sample was condensed by grouping all segments with an identical segment type, county ID, route type, route number, AADT, functional class, speed limit, lane width category, shoulder width category, presence of lighting, median type, TWLTL category, median width category, number of through lanes, presence of curb and gutter, and vertical grade. The query designs included the summation of several variables, including the lengths the aggregated segments, the three-year total of crashes assigned to each segment, the total number of driveways, and a count of the number of segments used to create each aggregated segment. Driveway density had to be recalculated after aggregation due the influence of segment length.

While the ideal driveway density for roadways is typically assumed to be less than five driveways per mile, Chapter 10 of the HSM warns that using actual driveway density for segments shorter than 0.5 mi can result in inflated values. As a result, it recommends the application of a general driveway density for a larger area to all nearby roadway segments. Due to the somewhat random distribution of segments analyzed for this project, driveway density had to be recorded by segment, and inflation was then accounted for by analyzing these driveway densities prior to running the crash prediction models. Using Equation 10-17 from Chapter 10 of the HSM, a predicted CMF was created for each segment in Figure 3.22 [AASHTO, 2010; Potts et al, 2007].

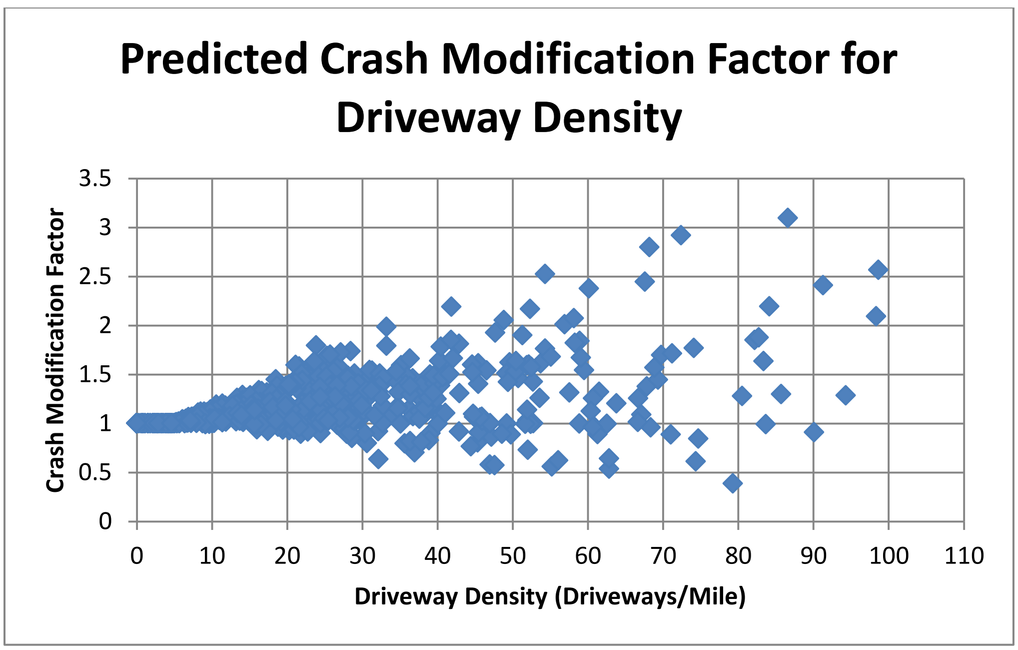

Figure 3.22: Predicted CMFs of Aggregated Segments based on Driveway Density

Based on the general trend of this chart, three relative categories were created for the inflated driveway densities:0-25 driveways/mi; 25-50 driveways/mi; and 50+ driveways/mi. For rural highways, no segments had driveway densities high enough to reach the 50+ driveways/mi category. Further discussion on the collection of driveway density is provided in the following section.

3.7.2 Statistical Methods and Considerations

Negative binomial distributions are considered to be an effective model to analyze the relationship between crash frequency, lane width, and many other roadway characteristics [Potts et al, 2007]. This model allows for the use of continuous, binary, and dependent variables and can help account for unusual or unexpected relationships between many variables and crash frequency. The analysis began by developing a base model for negative binomial regression using only traffic volume (AADT) as a predictor variable for crashes. The following model form is typical of most models provided in the Highway Safety Manual:

$$N = \exp(a + b \ln AADT + \ln L)$$

This base model was then expanded upon with a multi-variable models using numerous combinations of the total set of available variables depending on the segment type and assumed significant variables. The maximum form of the model would take the following form:

$$N = \exp(a + b \ln AADT + \ln L + c_{10} LW_{10} + c_{11} LW_{11} + c_{12} LW_{12} + d_0 SW_0 + d_2 SW_2 + e_{35-} S_{35-} + e_{40\text{-}45} S_{40\text{-}45} + e_{50\text{-}55} S_{50\text{-}55} + e_{60\text{-}65} S_{60\text{-}65} + f_{Low} DD_{Low} + f_{Med} DD_{Med} + g\, G + h\, LHT)$$

The variables for both models come directly from the sample of segments and are described below:

Continuous Variables

- Annual Average Daily Traffic [AADT, veh/day] – This variable was provided by SCDOT and was determined directly from the 2010 RIMS database. As a continuous variable, it was deemed appropriate to use the logarithmic function with this variable, as it tends to improve the model.
- Segment Length [L, mi] – Segments of varying length were developed during inventory and creation. All selected segments are greater than 0.1 mi long. As a continuous variable, it was deemed appropriate to use the logarithmic function with this variable, as it tends to improve the model. In addition, the coefficient of segment length was fixed at 1, as this was generally found to be true in previous research [Potts et al, 2007].

Categorical (Binary) Variables

- Lane Width Indicator Variables [LW, ft] – Lane width values were measured from the center of one pavement marking (typically a double yellow, single yellow, or single white) to the center of the next corresponding pavement marking or pavement edge. Ranges for categories include 9.5-10.5 ft, 10.5-11.5 ft, and 11.5-12.5 ft. Indicator variables were assigned a 1 if the segment fit into the appropriate lane width category. Otherwise, they were given a 0. The model was set up such that the ideal condition of 12 ft lanes was excluded, and the effect of other lane width variables was measured relative to that ideal condition.
- Shoulder Width Indicator Variables [SW, ft] – Only paved shoulders were considered for analysis, and these measurements were made from the center of one pavement marking (typically a double yellow, single yellow, or single white) to the pavement edge. Ranges for categories include 0-1 ft and 1-3 ft. Similar to the lane width indicator variable, values were given a 1 if the average shoulder width of a roadway segment was in the appropriate shoulder width category, and the segment was given a value of 0 otherwise. The SH_2 variable, similar to the LW_{12} variable, was excluded from the model and treated as the ideal condition.
- Speed Limit [S, mi/hr] – Speed limit was collected using video log recordings and field notes. Categories were created for speed ranges based on the spread of the sample. Ranges for categories include ≤35 mph, 40-45 mph, 50-55 mph, and 60-65 mph.

- Driveway Density [DD, driveways/mi] – This variable was collected using Bing Maps Aerials in ArcGIS. Driveway density incorporates all residential, commercial, and industrial driveways along each rural highway segment. In accordance with Chapter 10 of the HSM, all driveways that could be used on at least a daily basis for leaving the highway are considered [Highway Safety Manual, 2010]. Similar to speed limit, categories were created for driveway density based on the spread of the sample for all roadways. Ranges for categories include 0-25 driveways/mi, 25-50 driveways/mi, and 50+ driveways/mi. For rural highways, no segments had driveway densities high enough to each the 50+ driveways/mi category.
- Approximate Grade [G] – This was collected through visual inspection using the video log records. Segments were given a 0 for level terrain (< 3%) and a value of 1 for moderate terrain (3% < grade < 6%). The team did not encounter many rural roads with steep grades greater than 6%.
- On Street Lighting Indicator Variable [LHT] – This was determined using the video log recordings as an indicator variable. This variable was treated as a 1 if the segment had on street lighting and 0 if the segment lacked on street lighting.
- Roadside Features Indicator Variable [R] – Roadside features include paved shoulders as well as curb and gutter. Categories are developed for the four possible combinations: paved shoulder only, curb and gutter only, both, or neither. The appropriate indicator variable for each segment was determined using the video log recordings.
- TWLTL Width Indicator Variables [T, ft] – TWLTL width values were measured from the center of one TWLTL pavement marking (typically a double yellow with one solid line and one dashed line) to the center of the opposite TWLTL pavement marking. Ranges for categories include <14.5 ft and ≥14.5 ft for urban 3T and 5T roadway segments. Indicator variables were assigned a 1 if the segment fit into the appropriate lane width category. Otherwise, they were given a 0. The model was set up such that the ideal condition of ≥14.5 ft lanes was excluded, and the effect of other TWLTL width variable was measured relative to that ideal condition.

Dependent Variable

- Predicted Number of Crashes over three years [N, crashes/(3 years)] – These were determined from the provided crash records from 2007 to 2009. While an annual crash rate would be preferred in developing predicted values, initial trial models showed that the use of non-integers in the negative binomial model greatly altered its effectiveness.

The final sample of attributes associated with each segment is available electronically in Appendix B. Some variables were not considered for significance in all analyses due to the lack of a sufficient sample size. For example, a sufficient sample size of 10 ft lane segments was collected on 2U roadways but not 4D roadways. The negative binomial model was developed using R, Version 2.15.2. The results of the model and estimates for the model coefficients of each variable are included in Chapter 4.

4.0 Results and Discussion

4.1 Introduction

This chapter provides results and discussion from this study. The discussion is provided throughout to expand upon these results and tie them to the original goal and objectives described in Chapter 1. This chapter begins with a summary of the crash records from the geocoding process in section 4.2. The results of the operational effects of lane widths are discussed in section 4.3. The segment sample is discussed with some summary statistics in section 4.4, which ultimately leads to the results of the cross-sectional analysis in section 4.5. The analysis process was a critical element of this project and is most directly linked to achieving the overall goal and objectives of the project.

4.2 Crash Record Summary

The use of accurate crash records across several years is critical to safety analysis. The results below provide a summary of existing trends in South Carolina crash records, particularly as it relates to the crash record filtering process that is described in Chapter 3. Using the crash records on US, State, and Secondary routes from 2007 to 2009, the population of lane width-related crashes was queried for the nine chosen counties. Lane width-related crashes include all run-off-road, sideswipe (same and opposite direction), and head-on crashes. Figure 4.1 is a map of the final geocoded crash sample in the select nine counties. The map illustrates the spatial distribution of the selected counties from the upper, central, and coastal portions of South Carolina. Table 4.1 provides summary totals from the crash geocoding process.

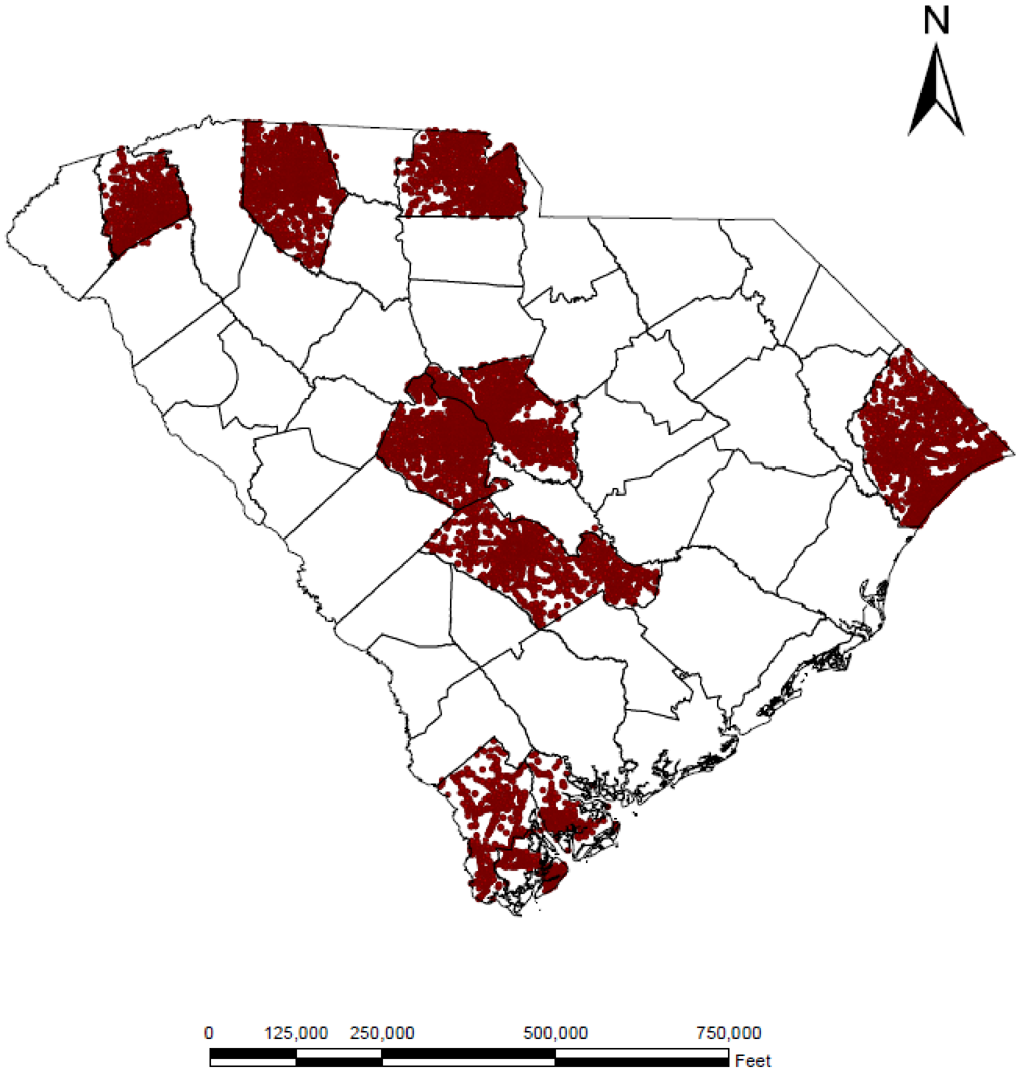

Figure 4.1: Map of Usable Crash Record Sample for the Selected Counties

Table 4.1: Total Crash Record Summary from 2007 to 2009

Scope	**Number of Records**
State	266,904
Selected 9 Counties	107,133
Lane Width Related Crashes in Selected Counties	29,991
Usable Lane Width Related Crashes in Selected Counties	27,939

As described previously, only certain types of crash records are considered to be potentially lane width related. Table 4.2 below provides a summary of the collision types within the sample. The majority of the sample crashes were run-off-the-road events. Note that additional angle crashes were added to the 5T analysis to account for TWLTL related crashes, which are not represented here.

Table 4.2: Lane Width Related Crash Records by Collision Type

Collision Type	Usable Records	% of Total
Run-off-the-Road	13,734	49.16
Head-On	5,756	20.60
Sideswipe, Same Direction	6,620	23.69
Sideswipe, Opposite Direction	1,829	6.55
TOTAL	27,939	100.00

The accuracy of the position information in the crash records differed by county. Many of the police jurisdictions within particular municipalities and counties were consistent in the accuracy with which crash records were collected. Table 4.3 below provides a crash record summary by county. This same breakdown of crash records is available by police jurisdiction in Appendix C.

Table 4.3: Lane Width Related Crash Records by County

County	Usable Amount	Unusable Amount	Total Amount	% Unusable
Beaufort	2056	135	2191	6.16%
Horry	4996	425	5421	7.84%
Jasper	628	117	745	15.70%
Lexington	3768	183	3951	4.63%
Orangeburg	2190	79	2269	3.48%
Pickens	1714	369	2083	17.71%
Richland	6172	107	6279	1.70%
Spartanburg	3514	532	4046	13.15%
York	2901	105	3006	3.49%
TOTAL	27939	2052	29991	6.84%

Additionally, as described in Chapters 2 and 3, there were many different reasons why a particular crash record would be considered usable or unusable. Table 4.4 provides a summary of these assessments for each year of geocoded crash records. Sarasua et al. [2008] provides a complete discussion of these classifications associated with similar study for data from the period 2004-2006. It was noted that the % of unusable crash location data has continued to increase each year since 2004.

Table 4.4: Lane Width Related Crash Record Totals for Selected Counties

	2007		2008		2009	
Coordinate Assessment	Amount	% of Total	Amount	% of Total	Amount	% of Total
TOTAL	**9817**	**100.00**	**10038**	**100.00**	**10136**	**100.00**
Coordinates in Degrees/Minutes/Seconds	8117	82.68	8027	79.97	7887	77.81
Coordinates in Decimal Degrees	467	4.76	476	4.74	543	5.36
Transposed LAT/LON Coordinates	8	0.08	74	0.74	79	0.78
Using Street and Intersection Information	628	6.40	758	7.55	875	8.63
Total usable	**9220**	**93.92**	**9335**	**93.00**	**9384**	**92.58**
Insufficient LAT/LON Precision (<6 characters)	172	1.75	155	1.54	169	1.67
Missing LAT, LON	248	2.53	285	2.84	280	2.76
Coordinates Out of Range	177	1.80	263	2.62	303	2.99
Total unusable	**597**	**6.08**	**703**	**7.00**	**752**	**7.42**

While crash records that were geocoded using street and intersection information are included in the usable records, it was not possible to locate these records using the coordinate information provided in the crash records in South Carolina. Furthermore, records listed as unusable were not geocoded using street and intersection information and therefore were not included in the sample.

4.3 Operational Analysis of Lane Widths

4.3.1 Operational analysis of lane widths at intersections

As described in Chapter 3, this research involved the use of a saturation flow rate study to investigate the operational effects of varying lane widths at signalized intersections. Signalized intersection operations are critical for interrupted flow facilities because they represent bottlenecks and are typically located in areas of highest congestion, particularly for urban roadways. Heavily congested unsignalized intersections are uncommon because their existence usually warrants a traffic signal. Examining the behavior of queues being released from signalized intersections provides a good indication of how traffic will behave at or near saturated conditions. Saturated conditions essentially represent the highest capacity that can be supported before an intersection begins to fail in terms of the level of service and are therefore ideal for the operational analysis.

Initial examination of the data collected on saturation flow rate for signalized intersections throughout South Carolina resulted in some concerns regarding the sample. First, the intersections studied are composed of several roadways with different functional classifications. While urban arterials make up the majority of sites identified for data collection, the sample includes many rural roadways, urban collectors, and roadways with unknown functional classes. Because the roadways were selected in the field based on traffic conditions and not from the RIMS, the data collection team collected data for several approaches that did not have a functional classification listed in RIMS. In general, there are very few signalized intersections on rural roadways thus the saturation flow study was conducted almost entirely using data from urban areas. A breakdown of the sites used in the saturation flow study is shown in Table 4.5. Saturation flow rates are analyzed for each of the lane types listed, but a few lane types from the original sample did not provide sufficient data for analysis, including double left-turn lanes, right-turn-only lanes, through lanes with a shared left-turn, and through lanes with a shared left- and right-turn component. The only type of shared lane included in the analysis is the through lane with a shared right-turn. Table 4.5 gives the number of observations for each of the different lane types by the functional classification. The column labeled “All” includes all functional classes grouped together, “Urban Arterials” is a subset of “All”, and further, “Urban Principal Arterials” is a subset of “Urban Arterials”.

Table 4.5: Breakdown of Measurements from the Saturation Flow Rate Study

	Functional Classification		
Total Measurements by Lane Type	**All**	**Urban Arterials**	**Urban Principal Arterials**
Through Lanes	238	185	85
Unskewed Left-Turn Lanes	86	53	31
Favorably Skewed Left-Turn Lanes	35	29	5
Unfavorably Skewed Left-Turn Lanes	28	28	13
Through (Shared) Lanes	114	92	40
Total Used	501	387	174
Other (Unused)	15	8	4
Overall Total	516	395	178

In addition to lane width and lane type, many other factors are considered in the study, including the number of vehicles recorded for each saturation headway measurement, and the influence of skewed intersections on saturation flow rate for left-turn lanes. Figures 4.2-4.4 show the relationship observed within the sample between lane width and saturation flow rate for through lanes. Although linear models are developed for these sets of data, many lack a significant relationship. Other models including exponential and logarithmic were analyzed but did not improve the results. In the following figures, the size of each data point corresponds to the number of vehicles involved in each saturation headway measurement.

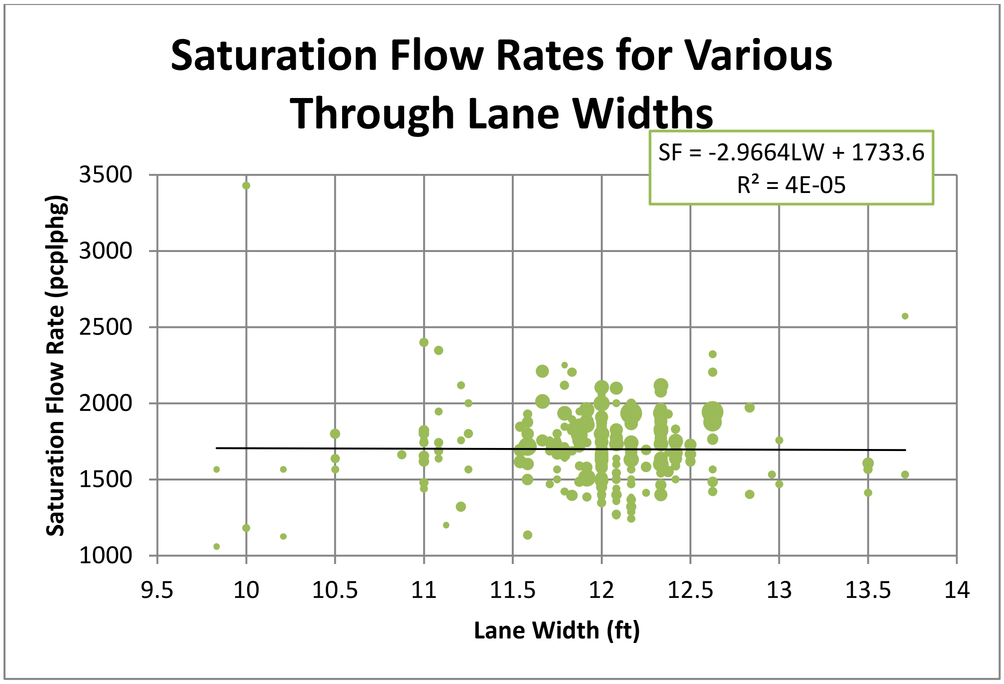

Figure 4.2: Saturation Flow Results for Through Lanes on All Roads

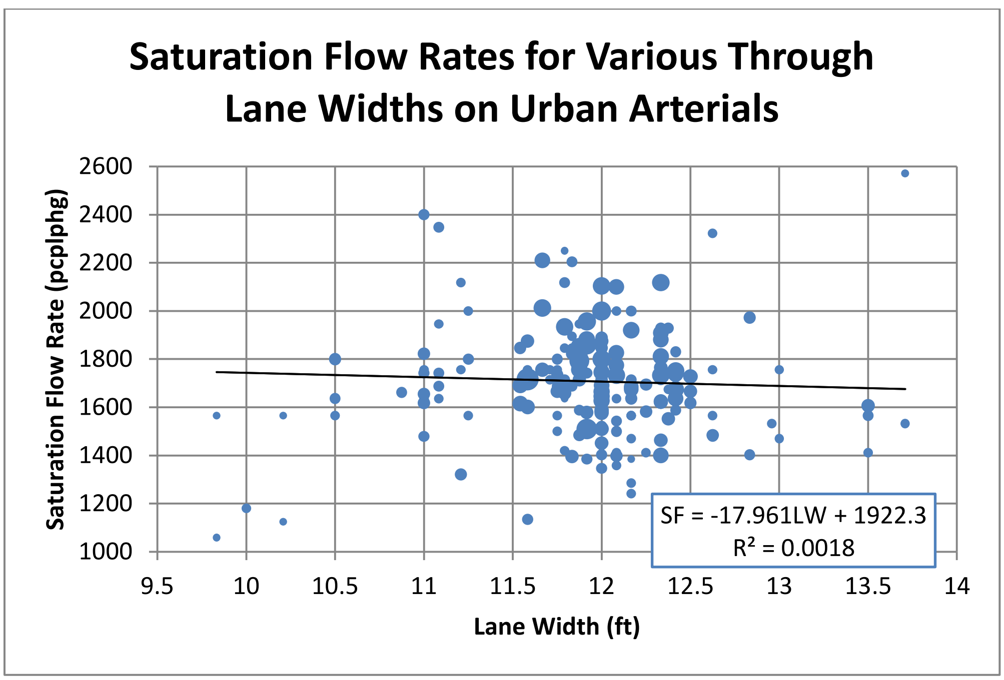

Figure 4.3: Saturation Flow Results for Through Lanes on Urban Arterials

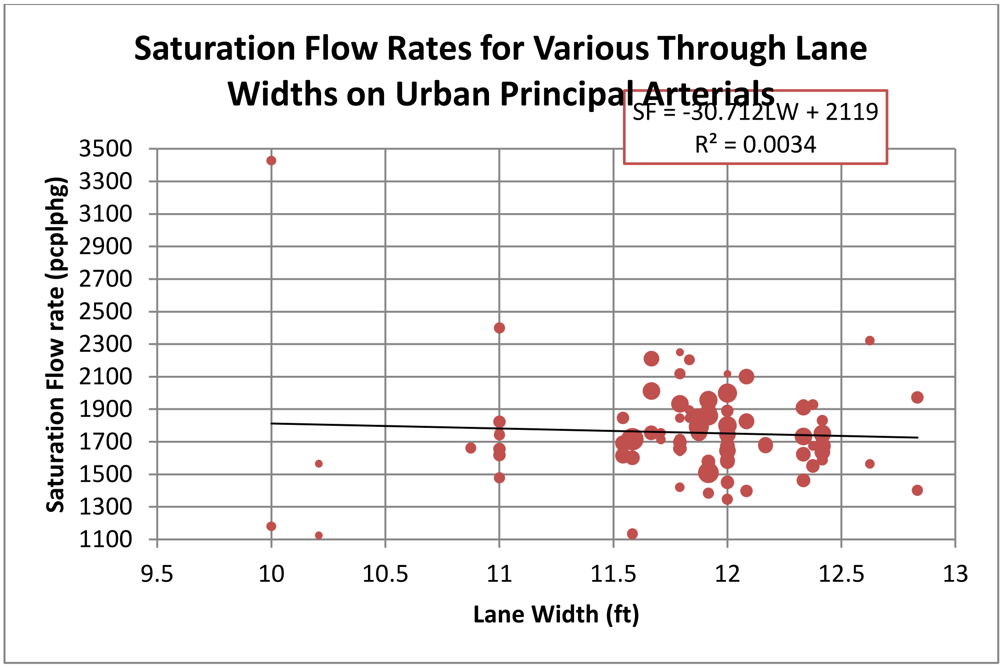

Figure 4.4: Saturation Flow Results for Through Lanes on Urban Principal Arterials

Conventional wisdom follows the trend that saturation flow rate for any particular lane should increase as the width of that lane increases. However, the data developed in this project suggests that little or no trend exists between these lane widths and saturation flow rate. In general, the data is scattered, and the trend line models appear to fit the data poorly and show no significant relationship. This is consistent with findings in the HCM that recommend no saturation flow rate adjustments be made for lane widths from 10 ft to 12.9 ft [HCM, 2011]. Due to the limited number of measurements for lane widths outside this range, no analysis could be conducted to compare findings in South Carolina with the recommended adjustment factors presented in the HCM for extremely wide or narrow lanes.

Comparing Figures 4.2-4.4 above, it appears that breaking the sample down into smaller subsets of functional classification does not improve the predictive power of the model. While the slope of the trend line becomes more negative by analyzing only urban principal arterials, it is not a significant change. It does not appear that the portion of the sample taken on minor roads is excessively skewing the results for through lanes. While these results are generally inconclusive for through lanes, the rest of the sample is analyzed using the same subsets of functional classification to determine whether or not other lane types behaved differently. The analysis for left-turn lanes at unskewed intersections followed similar trends as that for through lanes, and the results can be seen in Figures 4.5-4.7.

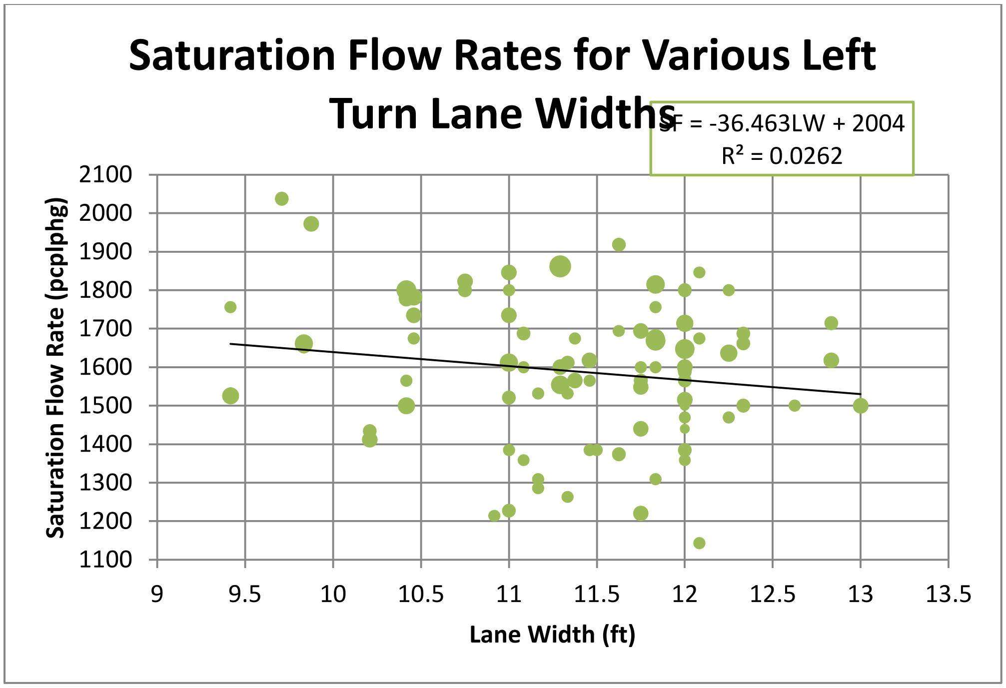

Figure 4.5: Results for Left-Turn Lanes on All Roads

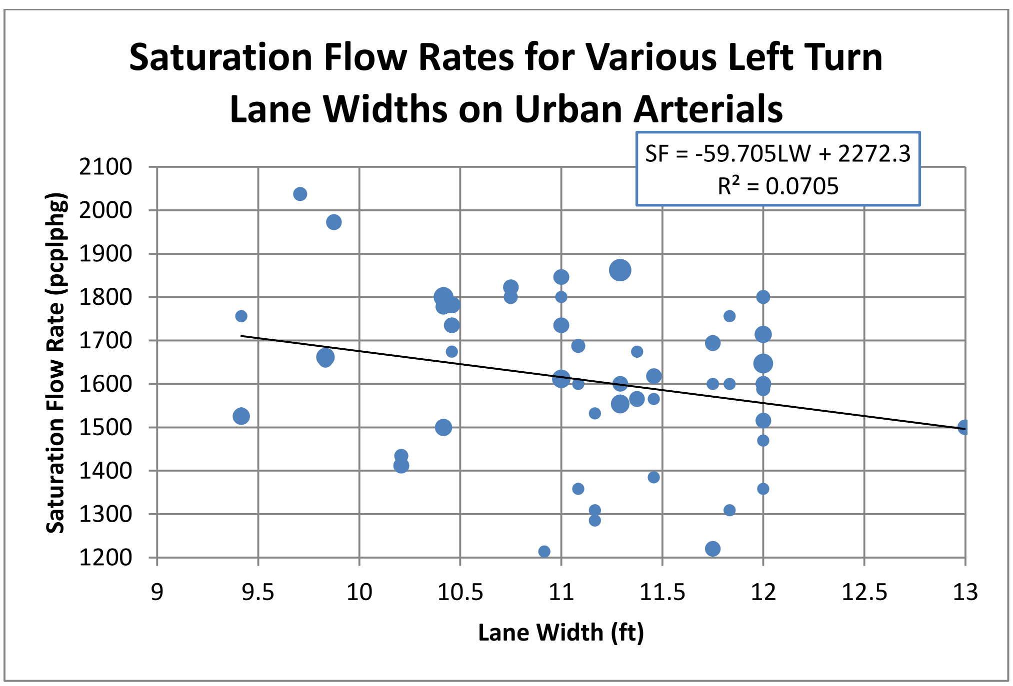

Figure 4.6: Results for Left-Turn Lanes on Urban Arterials

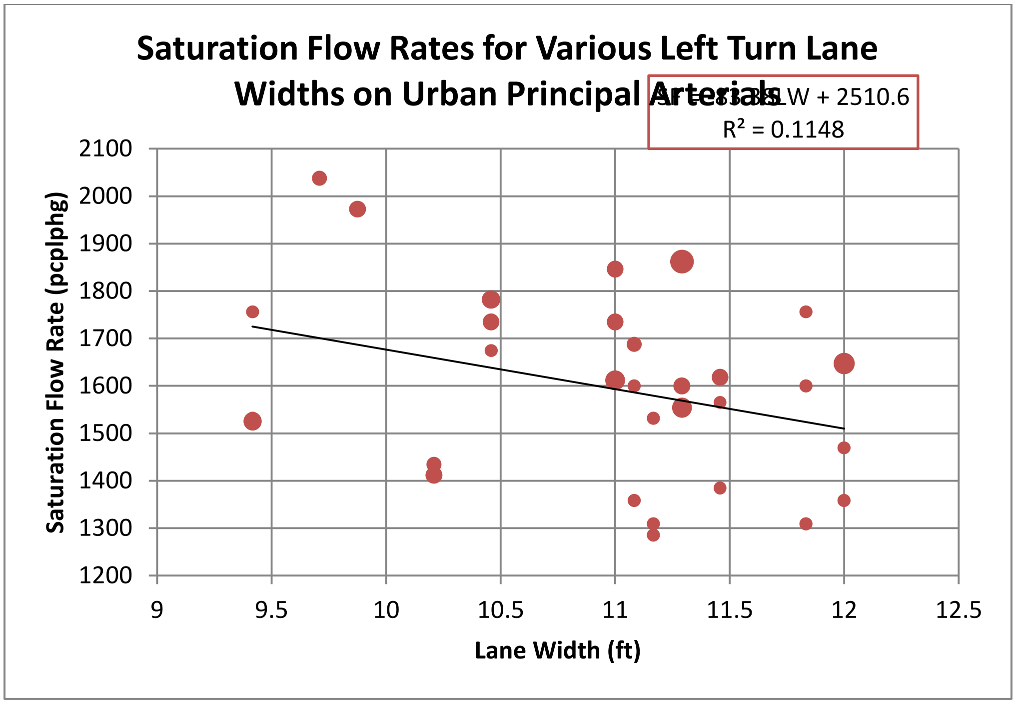

Figure 4.7: Results for Left-Turn Lanes on Urban Principal Arterials

Again, the data suggests little trend between left-turn lane width and saturation flow rate for each subset of functional class within the sample. In approaching the saturation flow rate analysis, the consideration is given to only analyzing the portion of the sample with a significant number of queue vehicles per measurement. By looking at the data in this manner, the group hoped that this sample might reflect “truer” saturation conditions within a specific lane. However, the results provide no indication that the number of queue vehicles within a particular measurement improves significance of the models.

The next set of analyses looked at the influence of skew at intersections on saturation flow rate for left-turn lanes. A comparison of favorably and unfavorably skewed left-turn lanes can be seen in Figures 4.8 and 4.9.

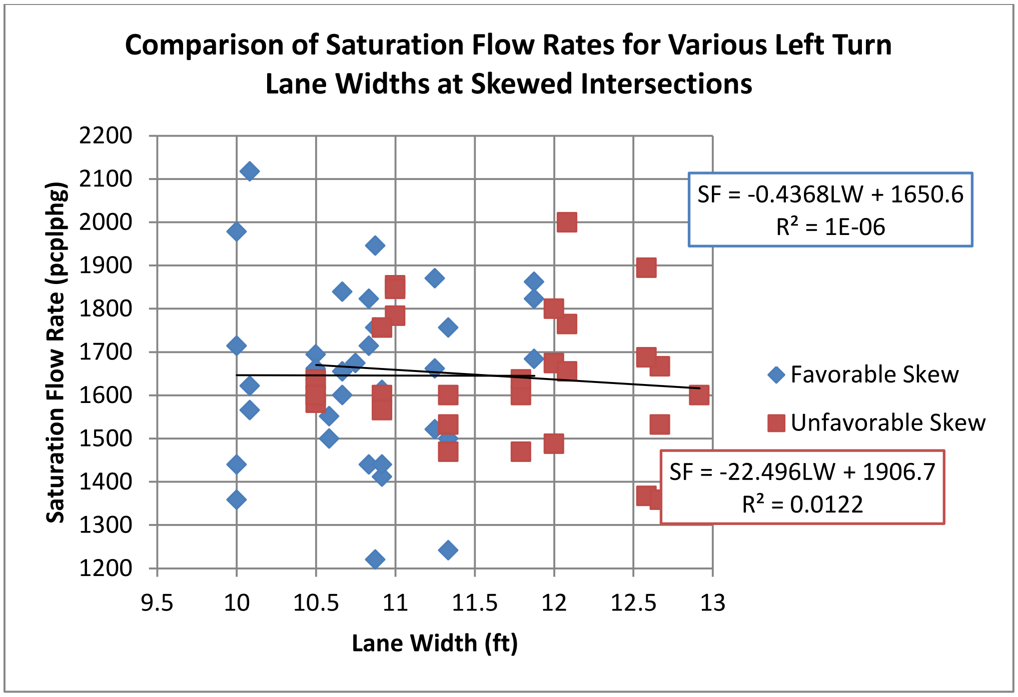

Figure 4.8: Results for Left-Turn Lanes and Skew on All Roads

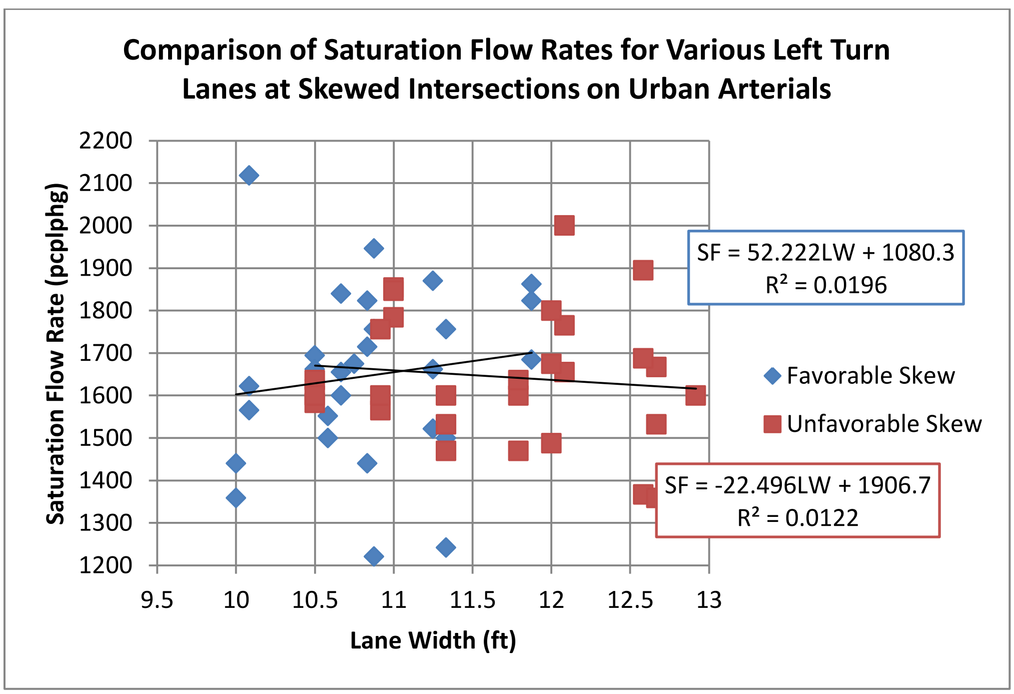

Figure 4.9: Results for Left-Turn Lanes and Skew on Urban Arterials

Skewed left-turn lanes are not analyzed for the subset of urban principal arterials due to an insufficient sample size. In general, significantly skewed intersections are avoided when selecting appropriate sites for this portion of the study. In addition, many of the skew angles for the intersections in the sample range from about 5° to 15°. While Figures 4.5-4.7 above reveal little trend between saturation flow rate and left-turn lane width, it is apparent that the favorably skewed left-turn lanes in the sample are generally narrower than their unfavorably skewed counterparts.

The final saturation flow analysis was conducted for a sample of approaches containing through lanes with a shared right-turn. Sampling and analyzing these lanes proved more challenging due to the unpredictability of turning vehicles. Field observations showed that turning vehicles typically increase the time required for a queue to progress through an intersection, as expected. Therefore, in analyzing these lanes, comparisons are made between saturation flow rates and both lane width and the percentage vehicles in the queue that turn. Similar charts to those seen above are provided for through lanes with a shared right-turn movement in Figures 4.10-4.12.

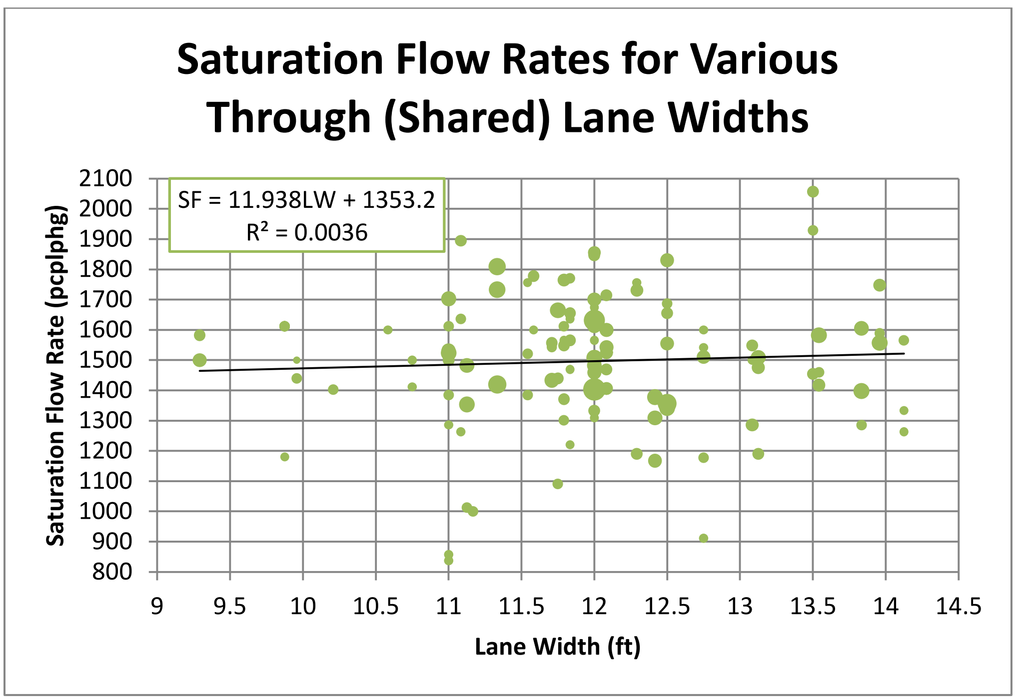

Figure 4.10: Results for Through (Shared) Lanes on All Roads

While the trend lines developed for these lanes still fit the data poorly, they do follow the conventional wisdom that wider lanes allow higher saturation flow rates. However, the fact that the percentage of turning vehicles varies greatly within the sample only adds to the seemingly random distribution of data. Figures 4.13-4.15 outline the influence that turning vehicles have on saturation flow rate.

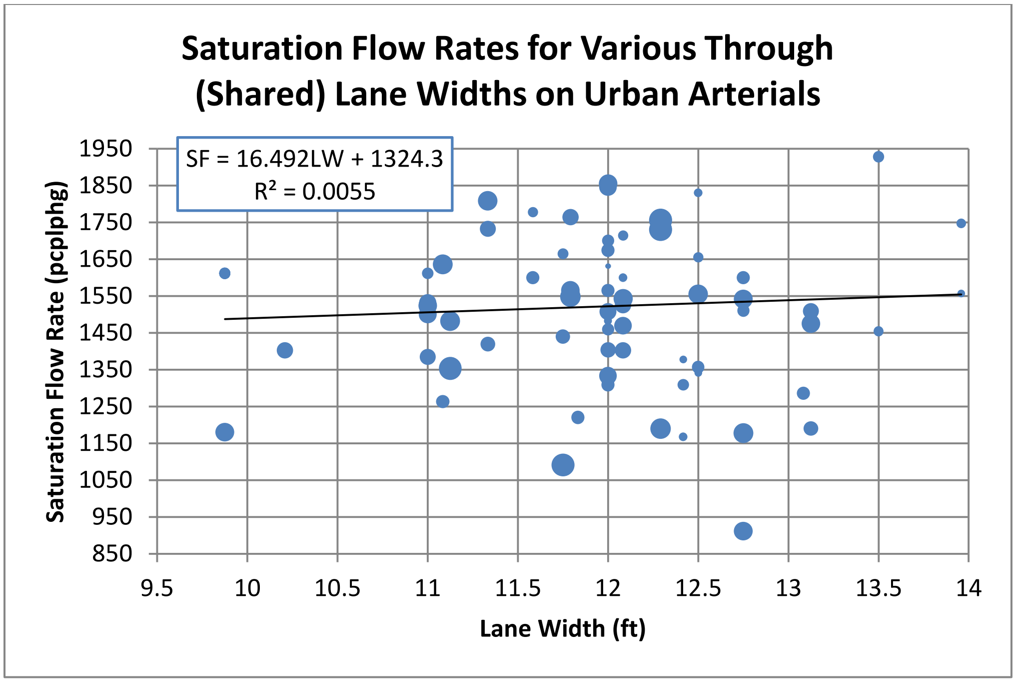

Figure 4.11: Results for Through (Shared) Lanes on Urban Arterials

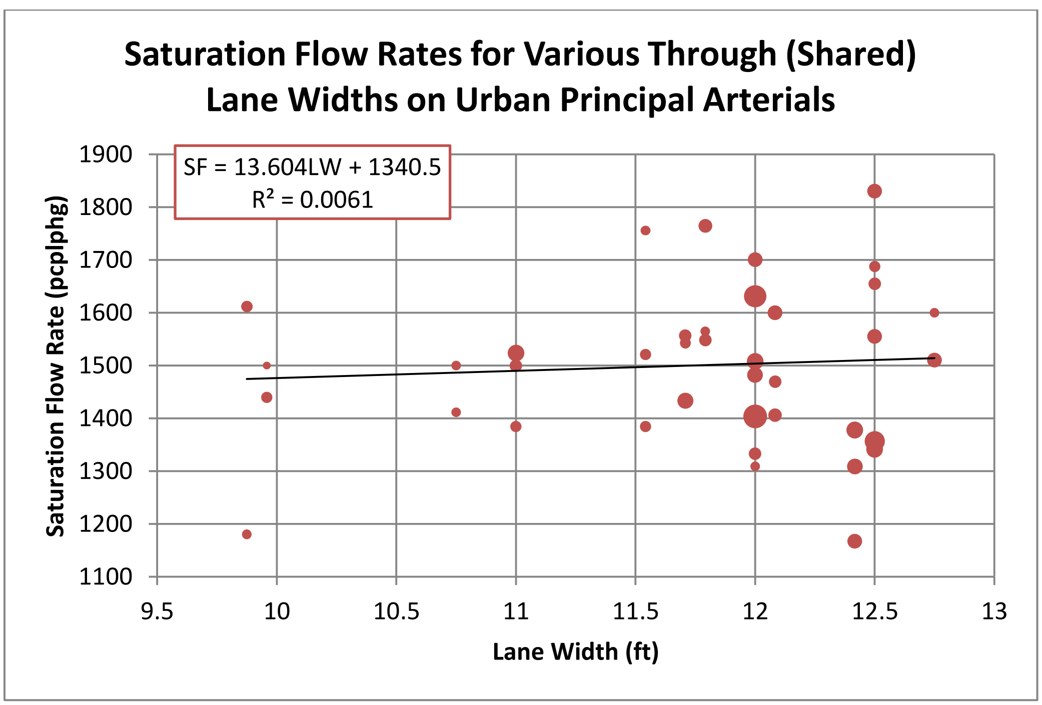

Figure 4.12: Results for Through (Shared) Lanes on Urban Principal Arterials

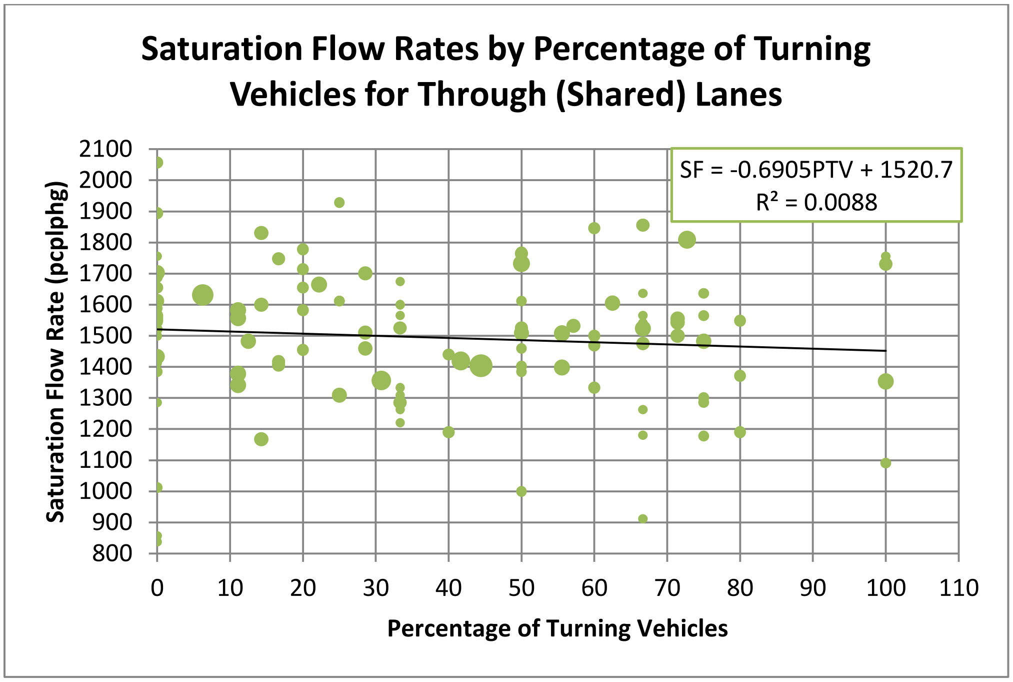

Figure 4.13: Analyzing the Percentage of Turning Vehicles on All Roads

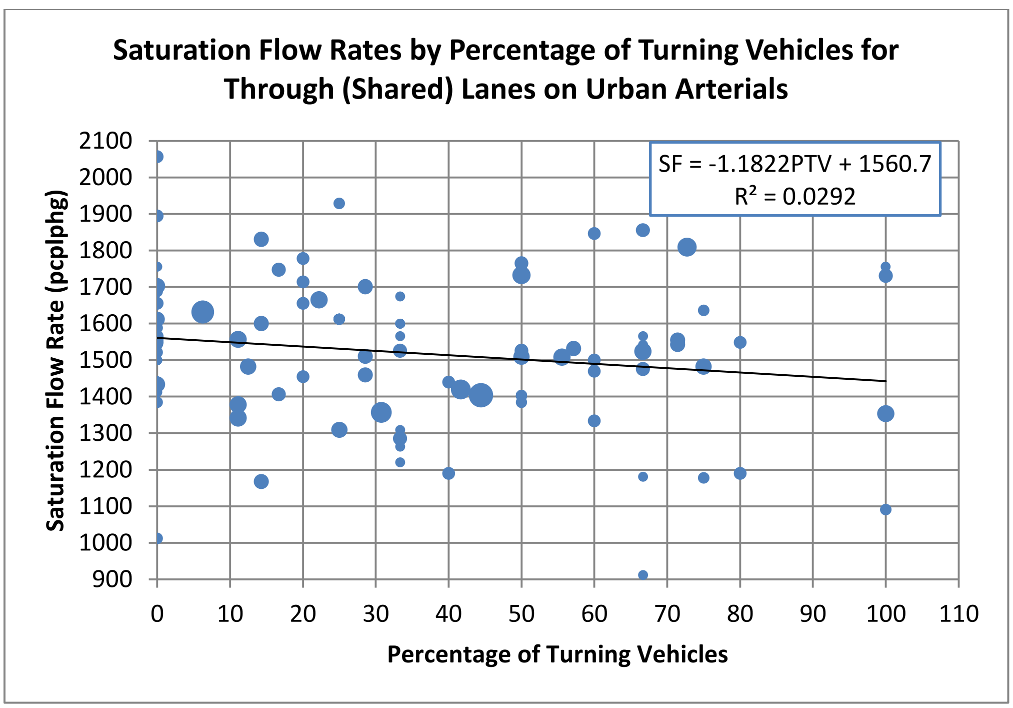

Figure 4.14: Analyzing the Percentage of Turning Vehicles on Urban Arterials

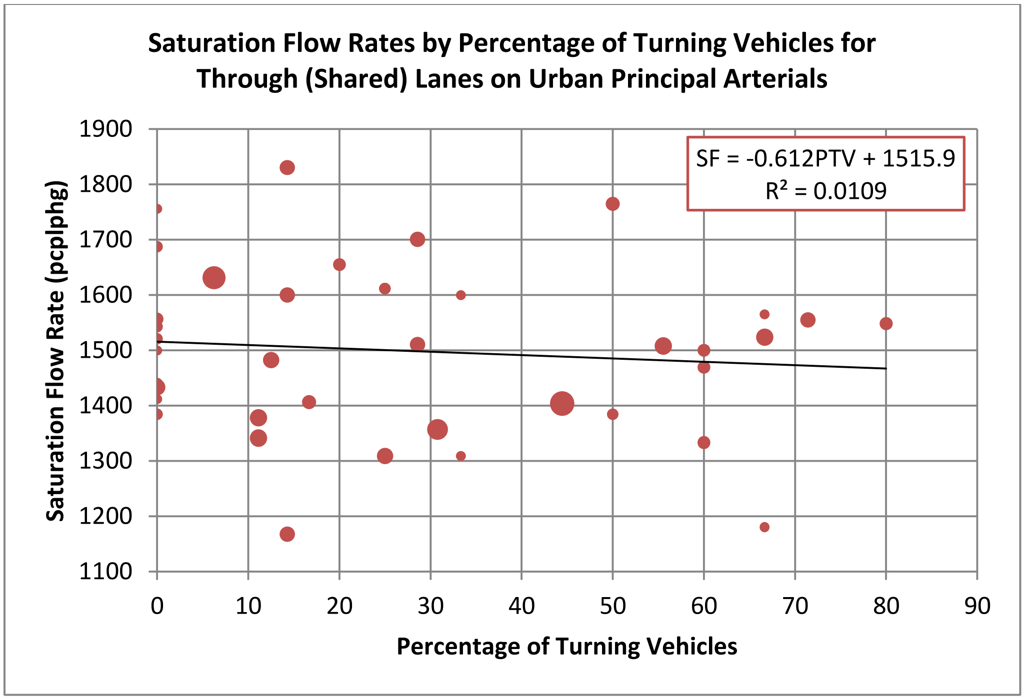

Figure 4.15: Analyzing the Percentage of Turning Vehicles on Urban Principal Arterials

While the linear trend lines still do not provide a great fit, these results suggest that saturation flow rate typically decreases as the percentage of turning vehicles in a queue increases. After diligent comparisons of the data from a wide variety of angles, the weighted average saturation flow rate for each lane type was considered. The weightings were based on the total number of queue vehicles in each measurement. These weighted averages are listed in Table 4.6.

Table 4.6: Weighted Average of Saturation Flow Rates by Lane Type

Lane Type	Weighted Average of Saturation Flow Rate (pcplph)	Saturation Headway (veh/sec)
Through Lanes	1735	2.08
Perpendicular Left-Turn Lanes	1618	2.23
Favorably Skewed Left-Turn Lanes	1684	2.14
Unfavorably Skewed Left-Turn Lanes	1697	2.12
Through (Shared) Lanes	1537	2.34

In analyzing the entire sample, through lanes had the highest weighted average of saturation flow rate. However, this value is considerably lower than the base saturation flow rate of 1900 pc/h/ln that is identified in the Highway Capacity Manual [2010]. This is to be expected because several adjustment factors not collected in the field are included in the equation for saturation flow rate seen below:

$$s = s_0 f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb}$$

In this equation, reductions are applied based on observed roadway characteristics including lane width, heavy vehicles, grade, parking, bus blockage, area type, lane utilization, turning vehicles, pedestrians and bicyclists [TRB, 2010]. For through (shared) lanes, the variation in percentages of turning vehicles is included to calculate a weighted average of saturation flow rate.

The behavior of skewed left-turn lanes proved to be somewhat unexpected because left-turn lanes at perpendicular intersections have lower saturation flow rates than both through lanes and favorably skewed left-turn lanes. While this is to be expected, the fact that unfavorably skewed left-turn lanes exhibited the highest saturation flow rate of all is not typical. This could be influenced by the generally wider lanes found at these sites, the limitation of the relatively small skew angles for skewed intersections, or any number of the other reduction factors that were not accounted for in this study.

Ultimately, the field study of saturation flow rate at signalized intersections resulted in no significant lane width relationships within the constraints of this study. It is possible that the somewhat ad hoc nature of selecting saturated intersections during the data collection process could have affected the overall results. If intersections were selected before data collection trips, and if specific approaches had been targeted to collect a more consistent sample of lane types and traffic volumes, the predictive nature of the results may have changed. However, these findings are consistent with the HCM which does not recommend the use of saturation flow rate adjustments for lane widths from 10 ft to 12.9 ft [TRB, 2010]. There were only a handful of observations with lane widths below 10 ft.

4.3.2 Operational Effects of Lane Widths for Highway Segments.

The researchers did not perform an empirical study of the effects of lane widths on multilane highways and two-lane road operations. The saturation flow study indicates that the findings of this research coincide with recommendations of the HCM. While intersections can be diverse in design and layout, multilane and two-lane highway designs usually follow similar design criteria for a particular functional class. The HCM accounts for variations in design criteria. It also provides recommendations to account for the effects of lane width and shoulder width through the use of free flow speed adjustment reduction factors on highways. These adjustments are discussed and tabulated in Chapter 2 and are not repeated here.

4.4 Segment Inventory Summary

The segment inventory process, including the collection of lane widths and many other site conditions, ultimately lead to the aggregation process and a final sample. This process was described in detail in Chapter 3 and is summarized below, including calibration results and a summary of the aggregation results.

4.4.1 Calibration Measurement and Results Summary

It was important to ensure that the measurements being made in the field were accurate such that substantial and meaningful conclusions could be made regarding lane widths in South Carolina. Table 4.7 provides calibration results between the lane widths collected with the rotating laser and widths collected using a measuring wheel at designated points throughout the state.

Table 4.7: Calibration Results for Lane Width Measurements

County	Avg. Percent Error
Pickens	1.49
Spartanburg	0.98
York	1.69
Lexington	1.48
Richland	1.26
Horry	1.18
Jasper	1.39
Beaufort	2.10
Orangeburg	1.92
TOTAL	1.50

Hand measurements were collected for a total of 26 calibration points across the 9 selected counties in the sample. The average percent error of 1.5% between laser and hand measurements equates to about 2 inches of error for a 12 ft lane. This is well within the 0.5 ft tolerance typically used to identify uniform lane widths that are rounded to the nearest foot. The speed and accuracy of the data collection indicate that the methodology used in this experiment can be quite beneficial in studying lane and shoulder widths.

4.4.2 Inventory Process, Aggregation, and the Final Sample

The bulk of the data collection was completed over the span of a few months during the spring and summer of 2012. The descriptive statistics of the segment data collection are provided in Table 4.8. The data collection mileage and time values do not include travel to and from sites. Route mileage is nearly double that of the sample due to the requirement to traverse multi-lane segments in both directions.

Table 4.8: Descriptive Statistics of Total Travel Required for Data Collection Routes

County	Route mileage (mi)	Time (hr)	Speed (mph)
Pickens	265.9	7.40	36
Spartanburg	505.9	14.23	36
York	356.7	10.43	34
Lexington	449.8	10.67	42
Richland	405.6	11.32	36
Horry	351.2	9.40	37
Beaufort/Jasper	451.7	10.93	41
Orangeburg	472.7	12.63	37
Total	3259.5	87.02	37

Many of the unforeseen difficulties with the RIMS attributes, as discussed in Chapter 3, made the data collection process a much more time-intensive process than originally anticipated. Despite the difficulties, the RIMS database served as the main source of data for the sample creation during the initial stages of the project. After segments were selected and verified into different HSM designations for road type, field attributes were collected for all of the selected segments. Table 4.9 summarizes the sample of roadways prior to field data collection. In general, a category was given to one of these RIMS segments if a significant portion of the segment was consistent with a particular type of roadway. Some of the issues regarding how roadways were segmented are discussed further in Chapter 5.

Table 4.9: Mileage Breakdown of Original Selected RIMS Segments by Segment Type

County	2D	2U	3T	4D	4U	5T	5T and 4D	TOTAL
Beaufort	0.74	42.28	5.33	33.13	-	22.81	7.55	111.84
Horry	-	84.73	1.52	102.84	-	23.26	3.02	215.37
Jasper	-	110.14	-	13.69	2.9	3.05	-	129.78
Lexington	-	102.9	2.37	13.68	-	58.51	-	177.46
Orangeburg	0.33	197.15	0.92	38.1	5.09	23.84	-	265.43
Pickens	-	97.93	1.15	27.18	5.58	9.19	1.77	142.8
Richland	-	118.09	1.4	34.2	2.59	25.54	-	181.82
Spartanburg	0.59	129.49	4.32	18.81	2.2	59.34	4.04	218.79
York	-	111.54	4.25	22.04	0.27	40.71	1.45	180.26
TOTAL	**1.66**	**994.25**	**21.26**	**303.67**	**18.63**	**266.25**	**17.83**	**1623.55**

After eliminating portions of the above segments based on inconsistent lane widths and the presence of intersections, a total of 1,292 roadway segments were found to be suitable for analysis. This is greatly reduced from the research teams' expectations. The primary contributor to this was inconsistent lane widths. Based on the laser data, if the lane width category assigned to a lane on one side of the road was not the same as that on the other, the lane width were considered inconsistent. Models could not be developed for roadway with 11 ft lanes on one side and 12 ft on the other. The one exception being wide outside lanes on multi-lane sections – if the total widths of both lanes on either side were the same, these are included and listed as inconsistent. However, these are not used in lane specific analyses rather only for turn lane analysis.

These samples were aggregated, as discussed in Chapter 3, to avoid overrepresentation of any one particular route or county. Basically, sections along the same route in the same county with the exact same characteristics were combined into one segment. Thus each route in each county with a particular set of lane width and shoulder width characteristics is represented only once in the sample. The aggregated sample is summarized in Table 4.10.

Table 4.10: Summary Results for Aggregation Process and Final Sample

Segment Type	Total Number of Segments	Total Number of Aggregated Segments	Total Length (mi)
Rural 2U	652	338	199.7
Rural 4D (Grass)	75	37	30.52
Rural 4D (Bituminous)	5	3	0.94
Urban 2U	116	75	34.51
Urban 3T	39	36	8.42
Urban 4D	17	13	4.38
Urban 4U	36	34	9.48
Urban 5T	352	257	101.08
Total	1292	793	389.03

Tables 4.8, 4.9, and 4.10 show a large discrepancy between the mileage of available roadway from the RIMS classifications, data collected, and the actual mileage used. There were a variety of issues contributing to this discrepancy. First, the inaccuracies within the RIMS database, particularly with how roadways were not segmented at intersections, led to the exclusion of significant portions of RIMS segments. In addition, other factors contributed to this discrepancy, including the elimination of roadways with inconsistently marked lane widths as well as the use of a 250 ft intersection buffer to select acceptable portions of roadways. Results of the aggregation process show that some categories of roadway type became less usable as the sample size was reduced. Typically, sample sizes below 30 will not produce significant results. Rural 4D segments with a bituminous median were eliminated completely from consideration for analysis because only 5 segments remained. Additional summary statistics for the final selected sample of aggregated segments are available in Tables 4.11 and 4.12 below. In all categories, the final sample consisted of 793 segments across 389 miles of roadway. The full sample of 793 segments is available electronically in Appendix B. Sample subsets, as described below, were created to complete the analysis.

Table 4.11: Number of Analysis Sites by Segment Type and Lane Width

	Lane Width (ft)								
Segment Type	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Inconsistent – wide outside lane**	**Total**
Rural 2U	-	2	53	164	114	5	-	-	338
Rural 4D (Grass)	-	-	-	9	29	1	-	1	40
Rural 4D (Bituminous)	-	-	-	-	5	-	-	-	5
Urban 2U	1	5	15	30	24	-	-	-	75
Urban 3T	-	-	2	5	12	10	4	3	36
Urban 4D	-	-	-	-	13	-	-	-	13
Urban 4U	-	1	3	3	7	3	-	17	34
Urban 5T	-	-	2	20	131	6	-	98	257

Table 4.12: Mileage of Analysis Sites by Roadway Type and Lane Width

	Lane Width (ft)								
Segment Type	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Inconsistent – wide outside lane**	**Total (mi)**
Rural 2U	-	0.48	21.6	104	70.7	3.42	-	-	199.7
Rural 4D (Grass)	-	-	-	6.72	23.4	0.25	-	0.13	30.52
Rural 4D (Bituminous)	-	-	-	-	0.94	-	-	-	0.94
Urban 2U	0.15	0.95	6.87	13.9	12.6	-	-	-	34.51
Urban 3T	-	-	0.37	0.99	2.57	1.87	2.34	0.26	8.42
Urban 4D	-	-	-	-	4.38	-	-	-	4.38
Urban 4U	-	0.22	0.54	0.5	2.45	1.15	-	4.61	9.48
Urban 5T	-	-	0.39	5.26	57.1	1.28	-	37.08	101.1

The vast majority of the sample is made up of 10-12 ft segments. As a result, no significant conclusions could be made regarding extremely narrow or wide lanes outside of this range. In approaching the analysis for the final sample, it was useful to consider the spread of the sample for three-year crash totals. Table 4.13 summarizes the distribution of crashes across different types of segments and lane widths.

Table 4.13 Total Number of Crashes by Segment Type and Lane Width

Segment Type	Lane Width (ft) 8	9	10	11	12	13	14	Inconsistent - wide outside lane	Total (mi)
Rural 2U	-	1	27	180	139	5	-	-	352
Rural 4D (Grass)	-	-	-	10	39	-	-	-	49
Rural 4D (Bituminous)	-	-	-	-	-	-	-	-	-
Urban 2U	-	1	18	31	25	-	-	-	75
Urban 3T	-	-	0	1	9	10	-	2	22
Urban 4D	-	-	-	-	20	-	-	-	20
Urban 4U	-	-	-	-	18	1	-	16	35
Urban 5T	-	-	1	15	212	4	-	127	359

Regarding the spread of the sample, roughly half of the segments across all segment types have zero crashes over the three years. The exception being Urban 5T which has only 30% with zero crashes over three years. Additionally, run-off-the-road crashes make up about 80% of the total number of crashes for the rural 2U, urban 2U, and rural 4D segments. Whereas, the urban 4D and 5T segments had approximately 30% run-off-the-road crashes, and urban 4U and 3T segments had less than 20% run-off-the road. Thus, rural 4D and all 2U had predominantly run-off-the-road crash experience, and urban roads (excepting 2U) had mostly multiple-vehicle crash experience (sideswipe and head-on).

Urban 5T segments account for the majority of urban sites used in this study. Many of the urban segments had consistent individual lane widths on either side of the centerline of the roadway. However, numerous sites were identified with wide outside lane designs, which produced inconsistency in individual travel lane widths that could not be accounted for in models assessing effects of lane width on crash experience. Therefore, 5T models were developed for lane widths as well as for total pavement widths. The following section outlines the results from each crash prediction model in more detail.

4.5 Cross-Sectional Analysis

The cross-sectional analysis conducted for this research project is intended to serve as the primary tool for comparing roadway safety with lane width. First, it is important to note that this is purely an observational study designed to investigate the correlation of roadway geometry and attributes with crash frequency. Ideally, a before-and-after study could be used in an effort to reveal whether or not the adjustment of a specific geometric attribute improves roadway safety. However, this is impractical as roadway improvement projects are rarely limited to a single change.

The overall model equation, which is described in Chapter 3, was used to determine how multiple site conditions can affect the safety of a roadway. For each model, two forms of the analysis equation were used. The first version represents the base model and only incorporates segment length and AADT relative to the predicted number of crashes. This is modeled after Equation 12-10 in Chapter 12 of the HSM. The general form of the negative binomial regression model is seen below [AASHTO, 2010]:

$$N = \exp (a + b \ln AADT + \ln L)$$

where:

- N = predicted number of crashes for three years of a specific crash type
- $AADT$ = average annual daily traffic volume (veh/day)
- L = roadway segment length in miles, and
- a, b = regression coefficients

The second version of each model includes many other variables of interest and corresponding regression coefficients. As described in Chapter 3, many of these variables act as categorical variables to define groups of particular site conditions. Coefficients for each of the variables included in the negative binomial model are provided in the summary tables. Positive coefficients indicate that roadways within a particular variable group would be expected to have higher crash rates than roadways with ideal conditions for that variable. For example, the c_{10} and c_{11} coefficients indicate how roadways with 10 and 11 ft lanes would be expected to behave relative to the ideal condition of 12 ft lanes. Each term is noted as having significant effect or not. A p-value of 0.1 was adopted for this study as it is a commonly accepted value, and given the relatively small sample size of segments, a p-value of 0.1 is large enough to allow for significant results at a 90% confidence level. Finally for each model, the overdispersion parameter is provided which gives an indication of model fit – closest to zero is best.

4.5.1 Cross-Sectional Analysis of Rural Highways

Numerous rural highway models were created for different samples of 2U segments and 4D segments. The Rural 2U sample size was significant for model development. However, the Rural 4D was made up predominantly of 12 ft segments which did not allow for good comparisons. For 2U segments, the models measured significance relative to the following ideal conditions:

- Lane widths of 12 ft
- Paved shoulder widths of 2 ft
- Speed limits of 50 or 55 mph
- Low driveway density (0-25 driveways/mi)
- Level terrain (< 3% grade)

The models for rural 4D segments were similar in nature but included fewer variables. The significance of the 4D models were measured relative to the following ideal conditions:

- Lane widths of 12 ft
- Paved outside shoulders of 2 ft
- Speed limits of 60 or 65 mph

4.5.1.1 Rural 2U Roadway Segments

The results for the analysis process on rural two-lane highways are provided below. In accordance with Objectives 1 and 2 from Chapter 1, the results below evaluate the use of narrower lanes and shoulders on both arterials and collectors. Additionally, these results provide the framework for the specific design recommendations on two-lane highways, which are provided in Chapter 5. Tables 4.14, 4.15, and 4.16 provide summaries of the base and full-variable model for all 2U segments. This model used the full sample of 2U segments and analyzes all variables with a sufficient sample size. Additionally, each variable was analyzed with total crashes, multi-vehicle crashes, and run-off-the-road crashes. This would allow for the targeting of specific variables based on crash type, and an analysis could be run that is consistent with past studies.

Table 4.14: Sample Breakdown of Variables on All Rural 2U Segments

Independent Variable	Coefficient	Number of Segments	Number of Crashes
Lane Width (ft)	c_{10}	53	27
	c_{11}	161	179
	c_{12}	109	136
Shoulder Width (ft)	d_0	222	224
	d_2	101	118
Speed Limit (mph)	e_{35-}	11	1
	e_{40-45}	86	63
	e_{50-55}	226	278
Driveway Density (Driveways/Mile)	f_{Low}	281	307
	f_{Med}	42	35
Moderate Grade	g	68	57

Table 4.15: Results for Base Model on All Rural 2U Segments

2U Base		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-2.12	0.91	0.020		-8.23	2.15	0.00013		-1.41	1.01	0.16	
AADT	b	0.32	0.11	0.0030	Yes	0.85	0.25	0.00075	Yes	0.21	0.12	0.078	Yes
Overdispersion Parameter	k	0.123				0.399				0.175			

Table 4.16: Results for Full-Variable Model on All Rural 2U Segments

2U Total		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-1.19	0.95	0.21		-6.77	2.24	0.0025		-0.61	1.08	0.57	
AADT	b	0.22	0.11	0.046	Yes	0.69	0.26	0.0082	Yes	0.13	0.13	0.31	No
Lane Width (ft)	c_{10}	-0.44	0.23	0.056	Yes	-0.92	0.63	0.15	No	-0.35	0.25	0.17	No
	c_{11}	-0.065	0.13	0.61	No	-0.13	0.28	0.66	No	-0.046	0.15	0.76	No
	c_{12}	0				0				0			
Shoulder Width (ft)	d_0	-0.15	0.13	0.24	No	-0.12	0.29	0.68	No	-0.16	0.15	0.28	No
	d_2	0				0				0			
Speed Limit (mph)	e_{35-}	-1.32	1.01	0.19	No	-30.46	2755000	1.00	No	-1.11	1.02	0.28	No
	e_{40-45}	0.14	0.16	0.35	No	-0.067	0.35	0.85	No	0.17	0.18	0.35	No
	e_{50-55}	0				0				0			
Driveway Density (Driveways/Mile)	f_{Low}	0				0				0			
	f_{Med}	0.30	0.20	0.12	No	0.93	0.35	0.0081	Yes	0.051	0.24	0.84	No
Moderate Grade	g	0.16	0.16	0.30	No	-0.012	0.38	0.98	No	0.20	0.18	0.25	No
Overdispersion Parameter	k	0.072				0.26				0.14			

The analysis results for the sample of 2U segments indicate only a few significant relationships across the entire set of field variables. The reduction of lane widths from 12 to 10 ft was found to reduce the frequency of crashes within this particular sample. Because this is contrary to the relationship found in previous research, it leads to questions regarding possible bias in the sample. By looking at the data further, some summary statistics were developed that help reveal the tendency of the selected 10 ft samples to have fewer crashes. Table 4.17 summarizes the bias in speed and average AADT values for each lane width category.

Table 4.17: Summary of Skew in Analyzing Lane Width on Rural 2U Sections

	12' lanes			11' lanes			10' lanes		
	#	%	Crashes/Mile	#	%	Crashes/Mile	#	%	Crashes/Mile
AADT									
<2000	5	4.4	0.40	13	7.9	1.82	10	18.9	1.44
2000-4000	40	35.1	1.37	46	28.0	2.20	20	37.7	1.85
>4000	69	60.5	2.61	105	64.0	1.82	23	43.4	1.85
SPEED									
30	0	0.0	--	1	0.6	0.00	0	0.0	--
35	2	1.8	0.00	6	3.7	0.27	3	5.7	--
40	0	0.0	--	3	1.8	0.39	0	0.0	--
45	22	19.3	1.89	35	21.3	2.41	30	56.6	2.73
50	1	0.9	2.24	5	3.0	3.55	8	15.1	1.13
55	89	78.1	2.17	114	69.5	1.85	12	22.6	0.21

The anomaly in the analysis results for lane width can most likely be explained by the fact that the sample segments with 10 ft lanes have significantly lower traffic volumes and speed limits than the sample segments with wider lanes. In fact, 56.6% of 10 ft lanes have less than 4000 AADT, whereas 60% or more of 11 ft and 12 ft lanes carry over 4000 AADT. Further, 77.4% of the speed limits on the 10 ft lanes are 50 mph or less, whereas the majority of 11 ft and 12 ft lanes have speeds of 55 mph. The lower traffic volumes and speeds ultimately result in smaller numbers of crashes. The overall average crashes/mile for this sample decrease from 12 ft lanes at 2.07, to 1.93 for 11 ft lanes, to 1.76 for 10 ft lanes. However, in the 45 mph speed bin (where most 10 ft sections are found) the crashes per mile increase as the lane widths decrease. Beyond lane width, the models summarized in Tables 4.15 and 4.16 show no other significant relationships except for the influence of excessive driveways on multi-vehicle crashes. The results for shoulder widths were not significant.

In analyzing previous research and observing some of the problem statements initially provided by SCDOT, it was decided to analyze a subset of 2U segments to look at the effect of total pavement width on crash frequency. Table 4.18 below provides a breakdown of the variables in the models to follow. Table 4.19 provides results for the analysis of segments with a total pavement width of 24 ft. Additionally, Table 4.20 provides analysis results for a subset of segments in which roadways with 28 ft of total pavement were compared to roadways with 24 ft of total pavement.

Table 4.18: Breakdown of Variables on Rural 2U Segments with Width Combinations

Independent Variable	Coefficient	Number of Segments	Number of Crashes
Total Pavement Width (ft)	k_{10-2}	18	12
	k_{12-0}	59	61
	k_{12-2}	50	75

Table 4.19: Total Pavement Model Results on 24 ft Rural 2U Segments

2U TP 24		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-6.12	2.34	0.0090		-9.49	5.07	0.061		-6.07	2.70	0.025	
AADT	b	0.79	0.28	0.0042	Yes	1.01	0.59	0.091	Yes	0.75	0.32	0.018	Yes
Total Pavement Width (ft)	k_{10-2}	-0.048	0.33	0.88	No	-0.29	0.76	0.71	No	0.032	0.37	0.93	No
	k_{12-0}	0				0				0			
Overdispersion Parameter	k	0.079				0.0011				0.17			

Table 4.20: Total Pavement Model Results on Rural 2U Segments with Width Combinations

2U TP Width Combos		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-4.87	1.60	0.0023		-10.17	3.48	0.0035		-4.19	1.82	0.021	
AADT	b	0.67	0.19	0.000292	Yes	1.11	0.40	0.0056	Yes	0.5655	0.2118	0.00759	Yes
TP Width Combos (ft)	k_{10-2}	-0.30	0.34	0.38	No	-0.45	0.81	0.58	No	-0.2724	0.3799	0.47	No
	k_{12-0}	-0.25	0.20	0.21	No	-0.12	0.43	0.78	No	-0.2931	0.2296	0.20	No
	k_{12-2}	0				0				0			
Overdispersion Parameter	k	0.17				0.65				0.24			

The results presented above for the total pavement studies indicate no significant relationships among lane and shoulder width combinations for a given total pavement width. As discussed in Chapter 2, a study by Gross et al. [2009] found a slight benefit to increasing lane width relative to shoulder width for a fixed total width. The same relationship is carried over into the Highway Safety Manual. In the HSM, ideal conditions are 12 ft lanes and 6 ft shoulders. Variations from the ideal values are adjusted using multiplicative Crash Modification Factors as shown in Table 4.21. As the Combined CMF increases, so too does the expected average crashes.

Table 4.21 Highway Safety Manual Combined CMF Vales by Lane and Shoulder Width

	Lane Width	Lane Width CMF	Shld Width	Shld Width CMF	Combined CMF
Case 1	12'	1	2'	1.3	1.3
Case 2	12'	1	0'	1.5	1.5
Case 3	10'	1.3	2'	1.3	1.69

4.5.1.2 Rural 4D Roadway Segments

The results for the analysis process on rural four-lane highways are provided below. In accordance with Objective 3 from Chapter 1, the results below evaluate the use of narrower lanes and shoulders on four-lane arterials. Additionally, these results provide the framework for the specific design recommendations provided in Chapter 5. Similar to the analysis process for 2U segments, considerations were made for lane width, shoulder width, and speed limit. Tables 4.22, 4.23, and 4.24 below summarize analysis results from the base and full-variable model for all 4D segments with a grass median. There were too few bituminous median samples to develop models for that segment type.

Table 4.22: Breakdown of Variables on All Rural 4D Segments

Independent Variable	Coefficient	Number of Segments	Number of Crashes
Lane Width (ft)	c_{11}	16	9
	c_{12}	46	32
Shoulder Width (ft)	d_0	31	18
	d_2	31	23
Speed Limit (mph)	$e_{50\text{-}55}$	7	2
	$e_{60\text{-}65}$	55	39

Table 4.23: Results for Base Model on All Rural 4D Segments

4D Base		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-10.22	3.08	0.000895		-17.89	7.37	0.015		-8.96	3.45	0.0094	
AADT	b	1.15	0.33	0.000463	Yes	1.80	0.78	0.020	Yes	0.99	0.37	0.0075	Yes
Overdispersion Parameter	k	0.00052				0.57				0.00016			

Table 4.24: Results for Full-Variable Model on All Rural 4D Segments

4D Total		Total Crashes				Multi-Vehicle				Run-off-the-Road			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-10.82	3.11	0.00050		-17.28	7.30	0.018		-9.88	3.50	0.0048	
AADT	b	1.21	0.33	0.000257	Yes	1.72	0.78	0.027	Yes	1.10	0.38	0.0035	Yes
Lane Width (ft)	c_{11}	-0.31	0.46	0.51	No	0.21	0.96	0.83	No	-0.47	0.55	0.39	No
	c_{12}	0				0				0			
Shoulder Width (ft)	d_0	0.17	0.39	0.66	No	0.22	0.90	0.81	No	0.13	0.43	0.77	No
	d_2	0				0				0			
Speed Limit (mph)	e_{50-55}	-0.70	0.74	0.34	No	0.034	1.15	0.98	No	-1.14	1.03	0.27	No
	e_{60-65}	0				0				0			
Overdispersion Parameter	k	0.0012				0.42				0.00014			

Similar to the analysis of the 2U segments, the analysis results for the sample of 4D segments do not indicate any significant relationships across the entire set of field variables with the exception of AADT. As shown in Table 4.22, there is little variability in lane width within the sample of 4D segments and a small number of 11 ft segments. Thus, a model could only be developed to compare segments with 11 or 12 ft lanes. As discussed in Chapter 2, the HSM CMFs for lane width on rural multilane highways show little difference between the use of 11 and 12 ft lanes, even on roads with a high AADT (HSM, 2010). Beyond lane width, the model indicated a tendency for reduced crashes on segments with lower speeds, although the relationship was not significant. Regarding shoulder width, few segments were collected with shoulder widths above 2 ft, simply because most of these facilities behaved more like freeway facilities with limited access and wide shoulders. As a result, an analysis could only be developed to compare no shoulder with 2 ft shoulders, and results from Table 4.35 show no significant influence.

4.5.2 Cross-Sectional Analysis of Urban Roadways

Numerous urban highway models were created for different samples of 2U, 3T, 4D, 4U, and 5T. Overall, the 2U and 5T had significant samples to allow for detailed models, whereas the sample sizes and mileage availability for other types were limited both in the sample as well as across the state. For Urban 2U segments, the models measured significance relative to the following ideal conditions (highlighted in sample output table as coefficient = 0):

- Lane widths of 12 ft
- Paved shoulder widths of 2 ft
- Speed limits of 50 or 55 mph
- Low driveway density (0-25 driveways/mi)

Table 4.25: Sample Full-Variable Model Output with Ideal Conditions Highlighted

2U Total		Total Crashes			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	*a*	0.62	2.19	0.78	-
AADT	*b*	7.73E-03	0.24	0.97	No
Lane Width (ft)	c_{10}	-0.1	0.37	0.78	No
	c_{11}	3.75E-03	0.31	0.99	No
	c_{12}	0			
Shoulder Width (ft)	d_0	-0.061	0.27	0.82	No
	d_2	0			
Speed Limit (mph)	e_{35-}	-0.66	0.68	0.33	No
	e_{40-45}	0.53	0.32	0.099	Yes
	e_{50-55}	0			
Driveway Density (Driveways/Mile)	f_{Low}	0			
	f_{Med}	0.92	0.4	0.021	Yes
	f_{High}	0.36	0.52	0.49	No
Overdispersion Parameter	*k*	1.29E-04			

4.5.2.1 Urban 2U Roadway Segments

Table 4.26 provides a summary of the number of segments within each of the various independent variable categories.

Table 4.26: Sample Breakdown of Variables on All Urban 2U Segments

Independent Variable	Coefficient	Number of Segments
Lane Width (ft)	c_{10}	14
	c_{11}	26
	c_{12}	20
Shoulder Width (ft)	d_0	37
	d_2	23
Speed Limit (mph)	e_{35-}	12
	e_{40-45}	34
	e_{50-55}	14
Driveway Density (Driveways/Mile)	f_{Low}	46
	f_{Med}	8
	f_{High}	6

Table 4.27: Results for Base Model on All Urban 2U Segments

2U Base		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-1.16	1.9	0.54	-	-8.84	4.7	0.06	-	-0.33	2.01	0.87	-
AADT	*b*	0.24	0.21	0.27	No	0.89	0.52	0.085	Yes	0.12	0.23	0.6	No
Overdispersion Parameter	*k*	0.12				0.15				0.1			

Table 4.27 and 4.28 summarize the results from the base model and full-variable model for Urban 2U roadway segments. Neither version of the model showed a significant correlation between AADT and predicted number of total crashes. Increased traffic is nearly always accompanied by an increased number of crashes, assuming that all other variables remain the same. However, the small sample could have played part in this insignificance as well as a general homogeneity in crash experience across the sample.

Table 4.28: Results for Full-Variable Model on All Urban 2U Segments

2U Total		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	a	0.62	2.19	0.78	-	-3.85	5.88	0.51	-	0.92	2.37	0.7	-
AADT	b	7.73E-03	0.24	0.97	No	0.23	0.63	0.71	No	-0.053	0.26	0.84	No
Lane Width (ft)	c_{10}	-0.1	0.37	0.78	No	-0.51	0.91	0.57	No	-0.035	0.4	0.93	No
	c_{11}	3.75E-03	0.31	0.99	No	-0.43	0.77	0.58	No	0.063	0.34	0.85	No
	c_{12}	0				0				0			
Shoulder Width (ft)	d_0	-0.061	0.27	0.82	No	0.11	0.73	0.88	No	-0.11	0.29	0.71	No
	d_2	0				0				0			
Speed Limit (mph)	e_{35-}	-0.66	0.68	0.33	No	-18.42	5.99E+03	1	No	-0.39	0.69	0.57	No
	e_{40-45}	0.53	0.32	0.099	Yes	0.99	0.96	0.3	No	0.45	0.34	0.19	No
	e_{50-55}	0				0				0			
Driveway Density (Driveways/Mile)	f_{Low}	0				0				0			
	f_{Med}	0.92	0.4	0.021	Yes	2.05	0.86	0.016	Yes	0.57	0.48	0.23	No
	f_{High}	0.36	0.52	0.49	No	1.71	1.05	0.1	Yes	-0.032	0.64	0.96	No
Overdispersion Parameter	k	1.29E-04				1.68E-04				2.01E-04			

Speed limits less than 35 mph are negatively correlated to crash frequency compared to speed limits between 50 and 55 mph, though insignificantly, but a statistically significant positive correlation can be seen for speed limits between 40 and 45 mph. For driveway density, a significant positive correlation indicates that crash frequency is higher for roadway segments with medium driveway density than for low driveway density. The insignificant results for high driveway density may be caused by the low number of segments that fell into that category.

A few small differences can be seen in the results from the crash prediction model for MV crashes on urban 2U segments. In this case, AADT is significant, but only for the AADT only base version of the model. Trends for driveway density are the same, and both low and high density are significant for MV crashes.

The model for ROTR crashes is more similar to the total crash prediction model. This is to be expected as Table 4.13 shows that the majority of crashes observed on urban 2U segments are ROTR crashes. The biggest difference is that statistical significance is no longer found for speed limit and driveway density. However, the behavior of each coefficient with respect to ideal conditions is identical to the total crash prediction model.

4.5.2.2 Urban 3T Roadway Segments

Tables 4.29 to 4.31 provide a similar analysis for urban 3T segments to the one seen above for urban 2U segments.

Table 4.29: Sample Breakdown of Variables on All Urban 3T Segments

Independent Variable	Coefficient	Number of Segments
Speed Limit (mph)	e_{35-}	21
	e_{40-45}	12
Driveway Density (Driveways/Mile)	f_{Low}	8
	f_{Med}	11
	f_{High}	14
Presence of Lighting	h (Yes)	9
	h (No)	24
Roadside	i_{CG}	19
	i_S	5
	i_N	4
	i_{CG+S}	5
TWLTL Width (ft)	j_{14-}	26
	j_{15+}	7

Table 4.30: Results for Base Model on All Urban 3T Segments

3T Base		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-7.89	4.94	0.11	-	-8.22	5.43	0.13	-	-8.8	11.85	0.46	-
AADT	*b*	0.97	0.52	0.059	Yes	0.99	0.57	0.082	Yes	0.89	1.24	0.47	No
Overdispersion Parameter	*k*	1.86E-04				1.36E-04				0.5			

Table 4.31: Results for Full-Variable Model on All Urban 3T Segments

3T Total		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-12.27	5.72	0.032	-	-10.68	6.23	0.087	-	-59.33	13200.00	1	-
AADT	b	1.31	0.59	0.026	Yes	1.12	0.64	0.082	Yes	4.24	2.63	0.11	No
Speed Limit (mph)	e_{35-}	0.9	0.76	0.24	No	0.9	0.86	0.3	No	0.57	1.62	0.73	No
	e_{40-}	0				0				0			
Driveway Density (Driveways/Mile)	f_{Low}	0				0				0			
	f_{Med}	-1.23	0.66	0.063	Yes	-0.98	0.69	0.15	No	-5.28	3.31	0.11	No
	f_{High}	-1.12	0.53	0.034	Yes	-1.18	0.58	0.041	Yes	-0.49	1.62	0.76	No
Presence of Lighting	h	0.047	0.63	0.94	No	-0.029	0.67	0.97	No	1.07	2.15	0.62	No
Roadside	i_{CG}	1.99	1.11	0.072	Yes	1.88	1.12	0.095	Yes	19.55	13200.00	1	No
	i_S	0.12	1.24	0.92	No	0.12	1.26	0.93	No	0.025	16300.00	1	No
	i_N	2.73	1.22	0.025	Yes	2.02	1.34	0.13	No	24.12	13200.00	1	No
	i_{CG+S}	0				0				0			
TWLTL Width (ft)	j_{14-}	-0.35	0.76	0.65	No	-0.067	0.88	0.94	No	1.74	2.30	0.45	No
	j_{15+}	0				0				0			
Overdispersion Parameter	k	4.60E-05				5.88E-05				7.04E-05			

For Urban 3T segments, AADT is found to have a statistically significant positive correlation with total crash frequency. In contrast to the Urban 2U model, as well as conventional wisdom, there appears to be a significant negative correlation between higher driveway density and crash frequency. The presence of roadside lighting was not significant for predicting crash frequency. In the full-variable model for total crashes, both the presence of curb and gutter only (with no shoulder) and the absence of both curb and gutter and shoulder features had significant positive coefficients with the latter having the highest one. Speed limit, presence of lighting, and TWLTL width were not significant predictors. In the multiple-vehicle crash model, the only significant variables were high density driveways and sections with curb and gutter only (without a shoulder). Again, increasing driveway density has increasingly negative relationship with crash experience. Whereas, the presence of curb and gutter only is positively correlated with crash frequency. As expected, this model yields similar results to the total crash model for urban 3T segments because most of the total crashes observed are MV crashes. The ROTR crash prediction model for urban 3T roadway segments yielded no significant correlations, largely due to the fact that only five crashes of this type occurred on the segments in this sample during the three year study period. This accounts for the abnormally large standard error and p-values near one.

It is worth noting that one of the variables excluded in the previous model is lane width. This is due to the lack of available segments for multiple lane widths categories as shown in Table 4.13. To generate some measure of lane width's relationship with crash frequency, a separate model is used with a subset of the original sample to compare the segments that meet or exceed the "ideal" total pavement width with those that do not. Only one segment from the original urban 3T sample is removed due to inconsistent lane widths on opposite sides of the road. The results from these model scan be found in Tables 4.32 and 4.33.

Table 4.32: Results for Base Model on Consistent Urban 3T Segments

3T Base 2		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-9.24	5.12	0.071	-	-9.97	5.67	0.078	-	-8.32	11.96	0.49	-
AADT	*b*	1.11	0.53	0.037	Yes	1.17	0.59	0.048	Yes	0.84	1.25	0.5	No
Overdispersion Parameter	*k*	1.70E-04				1.27E-04				0.52			

Table 4.33: Results for Ideal Pavement Width Model on Consistent Urban 3T Segments

3T Ideal TP Width		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-8.23	4.87	0.091	-	-9.33	5.58	0.094	-	-7.16	10.11	0.48	-
AADT	*b*	0.98	0.51	0.055	Yes	1.09	0.59	0.064	Yes	0.62	1.06	0.56	No
Ideal Pvt. Width Met (ft)	k_{No}	0.42	0.4	0.29	No	0.23	0.43	0.6	No	1.42	1.12	0.21	No
	k_{Yes}	0				0				0			
Overdispersion Parameter	*k*	9.62E-05				1.12E-04				9.08E-04			

For this model, AADT is positively and significantly correlated to crash frequency. While no significant correlation is found for the total pavement width with, it is worth noting that the coefficient for less than ideal total pavement width is positive, indicating a potential increase in crash frequency with lesser roadway widths**.** Results for the different crash types reveal little difference from the model for predicting total crashes except that AADT is not found to be significant for ROTR crashes. Again, the limited number of this crash type within the sample contributes to limited potential for significance.

4.5.2.3 Urban 4U Roadway Segments

Similar models to those created for 2U and 3T segments are outlined in the Table 4.56 for urban 4U segments except that lane width is not included in any form due to the general inconsistency of lane width observed in the field for this segment type.

In the base model (Table 4.35), AADT has a significant correlation to crash frequency, but it does not remain so in the model including all additional variables (Table 4.36). Speed follows the expected trend for this model, which is that reduced speeds are associated with lower crash frequencies. This is demonstrated through the statistically significant negative coefficient for the 35 mph and under speed limit category. No significant correlation is observed for driveway density or lighting, and only the absence of both paved shoulder and curb and gutter has a significant correlation among the roadside feature categories. However, the negative coefficient suggests that the absence of these features results in lower crash frequency, a trend completely reversed from the one found for urban 3T segments.

The MV crash prediction model is once again similar to the model for predicting total crashes due to the crash distribution throughout the sample. The only minor difference is the loss of significance for the coefficient of the 35 mph and under speed limit category.

Similar to the ROTR crash prediction model for urban 3T segments, the model for urban 4U segments results in relatively large standard errors for almost all independent variables and no significant correlation. This can also be due to lack of this crashes within the sample, in this case only four.

Table 4.34: Sample Breakdown of Variables on All Urban 4U Segments

Independent Variable	**Coefficient**	**Number of Segments**
Speed Limit (mph)	e_{35-}	21
	e_{40-45}	10
Driveway Density (Driveways/Mile)	f_{Low}	8
	f_{Med}	12
	f_{High}	11
Presence of Lighting	*h* (Yes)	17
	h (No)	14
Roadside	i_{CG}	18
	i_S	3
	i_N	4
	i_{CG+S}	6

Table 4.35: Results for Base Model on All Urban 4U Segments

4U Base		**Total Crashes**				**Multiple-Vehicle Crashes**				**Run-off-the-Road Crashes**			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	*a*	-8.77	4.74	0.064	-	-10.35	3.71	5.34E-03	-	-14.05	14.21	0.32	-
AADT	*b*	1.07	0.51	0.037	Yes	1.24	0.4	1.80E-03	Yes	1.42	1.53	0.35	No
Overdispersion Parameter	*k*	0.58				6.94E-04				5.26			

Table 4.36: Results for Full-Variable Model on All Urban 3T Segments

4U Total		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**	**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	a	-2.62	5.81	0.65	-	-3.7	6.08	0.54	-	3.35E+02	1.10E+05	1	-
AADT	b	0.58	0.59	0.32	No	0.66	0.61	0.28	No	-34.84	41.62	0.4	No
Speed Limit (mph)	e_{35-}	-1.34	0.7	0.057	Yes	-0.97	0.74	0.19	No	-84.33	1.24E+04	1	No
	$e_{40\text{-}45}$	0				0				0			
Driveway Density (Driveways/ Mile)	f_{Low}	0				0				0			
	f_{Med}	-0.33	0.87	0.7	No	-0.16	0.89	0.86	No	-47.61	1.06E+05	1	No
	f_{High}	0.21	0.68	0.75	No	0.34	0.69	0.62	No	-15.77	2.24E+04	1	No
Presence of Lighting	h	-0.23	0.51	0.66	No	-0.44	0.54	0.42	No	-2.17	1.02E+05	1	No
Roadside	i_{CG}	-0.75	0.54	0.17	No	-0.87	0.56	0.12	No	30.38	1.06E+05	1	No
	i_S	-1.34	1.14	0.24	No	-1.28	1.12	0.25	No	-41.73	1.15E+05	1	No
	i_N	-2.37	1.24	0.057	Yes	-2.04	1.24	0.1	Yes	-5.21	2.09E+05	1	No
	i_{CG+S}	0				0				0			
Overdispersion Parameter	k	1.21E-04				8.22E-05				5.47E-05			

4.5.2.3 Urban 5T Roadway Segments

The final segment type, urban 5T segments, consists of the largest sample size for urban road types. The approach for analyzing the correlation of lane width and crash frequency for these segments is slightly different than the model used for urban 3T segments and will be discussed along with the results for each model. In total, 3 sets of models will be described – one standard set with base and full variable models, one set which includes total pavement widths, and the final set which includes additional crashes, other than those associated with lane width to better determine the effects of TWLTL width on crash frequency.

Tables 4.37-4.39 provide the results from the overall analysis of independent variables on urban 5T segments. In this case, AADT is found to have a significant positive correlation with crash frequency. The 35 mph and under speed limit also has a statistically significant positive coefficient. The general trend for speed limit suggests that total crashes increase as speed limit decreases – this may reflect less access management on lower speed facilities. Only high driveway density has a significant positive coefficient value compared to low driveway density, but some inconsistency is still indicated by the fact that despite its statistical insignificance, the coefficient for medium driveway density is negative. The trends observed for roadside features are strikingly similar to the results from the model for urban 3T segments. Again, both the presence of curb and gutter only and the absence of both roadside features have significant positive coefficients with the latter having the highest one. The presence of paved shoulder only also has a positive but statistically insignificant coefficient. However, contrary to the results for the total crash prediction model for urban 3T segments, the less than ideal TWLTL width category has a positive yet insignificant coefficient.

Table 4.37: Sample Breakdown of Variables on All Urban 5T Segments

Independent Variable	Coefficient	Number of Segments
Speed Limit (mph)	e_{35-}	16
	e_{40-45}	189
	e_{50-55}	49
Driveway Density (Driveways/Mile)	f_{Low}	136
	f_{Med}	85
	f_{High}	33
Presence of Lighting	h (Yes)	219
	h (No)	35
Roadside	i_{CG}	178
	i_S	45
	i_N	15
	i_{CG+S}	16
TWLTL Width (ft)	j_{14-}	134
	j_{15+}	120

Table 4.38: Results for Base Model on All Urban 5T Segments

5T Base		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-9.81	1.54	2.00E-10	-	-14.45	1.95	1.31E-13	-	-3.81	2.04	0.063	-
AADT	b	1.14	0.16	3.78E-13	Yes	1.57	0.2	1.88E-15	Yes	0.41	0.21	0.053	Yes
Overdispersion Parameter	k	0.44				0.56				0.29			

Table 4.39: Results for Full-Variable Model on All Urban 5T Segments

5T Total		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	a	-8.91	1.64	5.16E-08	-	-12.99	2.02	1.30E-10	-	-3.81	2.32	0.1	-
AADT	b	0.93	0.17	3.36E-08	Yes	1.27	0.21	1.28E-09	Yes	0.35	0.24	0.14	No
Speed Limit (mph)	e_{35-}	0.62	0.35	0.077	Yes	1.14	0.42	6.75E-03	Yes	-0.32	0.65	0.62	No
	e_{40-45}	0.35	0.23	0.13	No	0.67	0.32	0.035	Yes	0.078	0.3	0.8	No
	e_{50-55}	0				0				0			
Driveway Density (Driveways/Mile)	f_{Low}	0				0				0			
	f_{Med}	-0.11	0.16	0.47	No	-0.053	0.18	0.77	No	-0.18	0.24	0.44	No
	f_{High}	0.47	0.21	0.023	Yes	0.5	0.23	0.029	Yes	0.35	0.34	0.3	No
Presence of Lighting	h	-0.06	0.21	0.78	No	0.097	0.23	0.67	No	-0.62	0.42	0.14	No
Roadside	i_{CG}	0.81	0.36	0.025	Yes	0.84	0.43	0.051	Yes	0.63	0.55	0.25	No
	i_S	0.48	0.42	0.25	No	0.36	0.52	0.48	No	0.43	0.61	0.49	No
	i_N	1.25	0.45	5.87E-03	Yes	1.27	0.53	0.017	Yes	0.99	0.69	0.15	No
	i_{CG+S}	0				0				0			
TWLTL Width (ft)	j_{14-}	0.06	0.14	0.67	No	0.15	0.16	0.37	No	-0.063	0.21	0.76	No
	j_{15+}	0				0				0			
Overdispersion Parameter	k	0.3				0.3				0.22			

The sample used in these models has a higher percentage of ROTR crashes than the samples of urban 3T segments and urban 4U segments, but the MV crash prediction model here still reflects the same trends as the total crash prediction model, and for the most part, even the same significant independent variables. The only exception is that the coefficient for the 40-45 mph speed limit category is actually significant in this model.

Despite the relatively higher percentage of ROTR crashes in this sample, the ROTR crash prediction model for urban 5T segments still yielded no statistically significant coefficients apart from AADT in the AADT only version of the model. As was the case for the urban 3T segments, the sign of the coefficient for the less than ideal TWLTL width category is again different for the ROTR crash prediction model that it was for the other two models. However, the sign change for the urban 5T segments is the complete opposite, and these values are all close enough to zero that this interesting observation likely has little meaning.

As mentioned earlier, the second model created for urban 5T segments to incorporate lane width into the analysis differs from the second model used to analyze urban 3T segments. Due to the predominance of segments with 12 ft lane widths among the 5T segments with consistent lane widths, four separate categories are used to consider any correlations that might exist between lane width, including TWLTL width, and crash frequency. The first category is for segments with lane widths under 12 ft and a total pavement width that does not meet the “ideal” conditions. The second category includes all segments with 12 ft lanes that have a TWLTL less than 15 ft wide. Only the “ideal” conditions of 12 ft lane width and 15 ft TWLTL width are represented in the third category. The last category is comprised of only those segments that exceed the ideal total pavement width and have at least 12 ft lane widths. This does include some segments with a TWLTL width below 15 ft that still exceed the ideal total pavement width. The results from the model developed to analyze these factors can be seen in Table 4.40.

Table 4.40: Results for Ideal Pavement Width Model on All Urban 5T Segments

5T Ideal TP Width		Total Crashes				Multiple-Vehicle Crashes				Run-off-the-Road Crashes			
Independent Variables		Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant	Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-9.47	2.12	8.13E-06	-	-12.23	2.69	5.69E-06	-	-5.3	3.19	0.097	-
AADT	*b*	1.12	0.21	1.64E-07	Yes	1.37	0.27	4.26E-07	Yes	0.55	0.32	0.088	Yes
Ideal Pavement Width Met (ft)	k_U	-0.22	0.39	0.58	No	-0.045	0.45	0.92	No	-1.09	1.03	0.29	No
	k_{TU}	0.063	0.21	0.76	No	0.079	0.26	0.76	No	-5.39E-03	0.34	0.99	No
	k_O	0.052	0.27	0.85	No	-0.23	0.36	0.52	No	0.6	0.36	0.097	Yes
	k_I	0				0				0			
Overdispersion Parameter	*k*	0.25				0.46				4.68E-04			

The model clearly shows that AADT has a significant positive correlation with crash frequency. However, no significant correlation is present for the different total pavement width conditions. The category with, theoretically, the worst conditions actually has a negative coefficient, indicating a lower crash frequency.

While all correlations described by this model are still statistically insignificant, the most notable difference observed for the MV crash prediction model is that the coefficient for the category that exceeds total pavement width is negative, suggesting that larger pavement widths are associated with lower MV crash frequency.

The difference in the ROTR crash prediction model is that the coefficient for the over ideal pavement width category is both positive and significant, indicating that segments with excess pavement width are simultaneously associated with decreased MV crashes and increased run-off-the road crashes.

After running all the models for 5T segments, the team decided that some of the crash types originally eliminated might, in fact, be lane width related on segments with a TWLTL. After adding rear end and angle crashes to the study and attributing them to the new segments, the same models were developed for 5T segments to predicted total crashes, including the additional crash types. The results are shown below in Tables 4.41-4.4.44.

Table 4.41: AADT Only Additional Crash Prediction Model for Urban 5T Segments

5T Base		Total Crashes (Including Additional Angle Crashes)			
Independent Variables		Coefficient	Std. Error	P-value	Significant
Intercept	*a*	-13.26	1.39	< 2E-16	-
AADT	*b*	1.63	0.14	< 2E-16	Yes
Overdispersion Parameter	*k*	0.75			

Table 4.42: Overall Additional Crash Prediction Model for Urban 5T Segments

5T Total		**Total Crashes (Including Additional Angle Crashes)**			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	a	-11.71	1.37	< 2E-16	-
AADT	b	1.37	0.14	< 2E-16	Yes
Speed Limit (mph)	e_{35-}	0.62	0.29	0.032	Yes
	e_{40-45}	0.35	0.19	0.067	Yes
	e_{50-55}	0			
Driveway Density (Driveways/Mile)	f_{Low}	0			
	f_{Med}	0.37	0.13	4.94E-03	Yes
	f_{High}	0.87	0.18	8.22E-07	Yes
Presence of Lighting	h	-0.045	0.17	0.79	No
Roadside	i_{CG}	0.41	0.25	0.11	No
	i_S	-0.091	0.30	0.76	No
	i_N	0.76	0.35	0.028	Yes
	i_{CG+S}	0			
TWLTL Width (ft)	j_{14-}	0.083	0.12	0.48	No
	j_{15+}	0			
Overdispersion Parameter	k	0.51			

Table 4.43: AADT Only Additional Crash Prediction Model for Urban 5T TP Width

5T Base 2		**Total Crashes (Including Additional Angle Crashes)**			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	a	-11.76	2.12	2.70E-08	-
AADT	b	1.51	0.22	3.11E-12	Yes
Overdispersion Parameter	k	0.77			

Table 4.44: Overall Additional Crash Prediction Model for Urban 5T TP Width

5T Ideal TP Width		**Total Crashes (Including Additional Angle Crashes)**			
Independent Variables		**Coefficient**	**Std. Error**	**P-value**	**Significant**
Intercept	a	-11.55	2.09	3.25E-08	-
AADT	b	1.49	0.21	2.03E-12	Yes
Ideal Pavement Width Met (ft)	k_U	-0.57	0.35	0.11	No
	k_{TU}	0.087	0.22	0.69	No
	k_O	-0.45	0.28	0.11	No
	k_I	0			
Overdispersion Parameter	k	0.73			

These analysis models did not show many trends vastly different from the ones observed in the original total crash prediction models. The coefficient for medium driveway density in the overall model changed from negative to positive and became significant, following the expected trend. The coefficient for roadside with shoulder only also became positive but not significantly. All roadside feature categories followed the same relative trend as seen in the original total crash prediction model. For the new ideal total pavement model, the over ideal and under ideal coefficients both became more negative and nearly significant, indicating an inconsistent trend where crashes are less likely for both of these circumstances compared to roadway segments with ideal lane and TWLTL widths.

4.6 Summary Results and Discussion

The success of the analysis process was, in many ways, dependent on successfully geocoding the desired lane width related crashes in South Carolina. The sample of crash records, which are summarized in section 4.2, ultimately played a critical role in trying to develop meaningful results regarding lane widths. The segment inventory, summarized in section 4.3, introduces some of the tendencies in the sample regarding geometric data and the associated crash records. It was found that certain bias exist within the sample, particularly as it relates to limited variability in the number of crashes across multiple segments. Most of the segments in the sample have between zero and two crashes over a three-year span, which makes the determination of significant variables unlikely.

The cross sectional analysis results described in 4.5.1 show little significant influence of lane and shoulder width on the safety of rural highways. Past studies have found decreases in lane width increases crash rate, particularly on roads with large traffic volumes and higher speeds. Some of the results in this study, including the tendency for 10 ft lanes to reduce crashes on rural 2U segments, can be explained by bias present in the sample. The majority of the sample segments with 10 ft lanes had significantly lower traffic volumes and travel speeds than the segments with 11 and 12 ft lanes. To develop meaningful conclusions regarding the application of flexible lane widths across the state, it will be critical to understand the impact of using narrower lanes on those roadways with high traffic volumes.

Many of the other variables with insignificant relationships in the sample simply stem from the lack of a sufficient sample size in particular rural categories. For example, there were large discrepancies in sample size for rural 4D segments in the lane width and speed categories. Additionally, the rural 4D sample could only be analyzed with 11 and 12 ft lanes, which typically show little variation in crash frequency.

Due to limited sample size among some of the urban segment types, many of the crash prediction models yield statistically insignificant results for urban roads. But these results can still be compared relative to other variables and other models. For total crashes on urban 2U segments, no difference can be seen between 11 and 12 ft lanes in terms of correlation with crash frequency. A negative but statistically insignificant regression coefficient is observed for 10 ft lanes. Also, no significant correlation exists between shoulder width and crash frequency. The only statistically significant coefficients are medium driveway density and speed limits from 40-45 mph, both of which have positive values. These trends remain in the urban run-off-the-road crash prediction model, but in the urban multiple-vehicle crash model, speed limit becomes insignificant, while the positive high driveway density coefficient becomes significant in addition to the one for medium driveway density. AADT is also observed to have a significant positive coefficient, but only in the AADT only model.

For total crashes on urban 3T segments, the regression coefficient for AADT is again positive and significant. Lower speed limits have a positive but insignificant correlation to crash frequency while higher driveway densities have statistically significant negative coefficients. The data reveals little correlation for urban TWLTL width, but a general trend is apparent for the roadside features. The categories for paved shoulder only, curb and gutter only, and neither shoulder nor curb and gutter are all positively correlated with crash frequency in order of increasing magnitude, and the latter two are both significant. The urban multiple-vehicle model yields similar results, and the urban run-off-the road model reveals almost no significance due to the crash distribution within the sample. Analysis of total pavement width on urban 3T segments shows a positive correlation between narrower roads and frequency of all crash types, but all coefficients are statistically insignificant apart from AADT.

Limited sample size for urban 4U segments limits the amount of significant results yet again. The absence of both curb and gutter is found to be significant for a few of the models but follows the opposite trend to that observed for urban 3T segments. AADT is also significant and positively correlated to crash frequency for two of the AADT only models.

Analysis of urban 5T segments produces results similar to those seen for 3T segments. Positive coefficients are observed for AADT, low speed limit, and high driveway density. Also, the roadside feature categories behave similar to those for 3T segments in both sign and statistical significance. However, little significance is revealed for TWLTL width. Analysis of total pavement width on urban 5T segments shows that AADT is significant for most models. The regression coefficient for pavement width in excess of ideal conditions is simultaneously negative for multiple-vehicle crashes and positive for run-off-the-road crashes, but only the latter is significant. Additional models developed to include rear end and angle crashes on 5T segments in total crash prediction reveal no new trends that vary greatly from the original models.

The results of the different analyses discussed in this chapter ultimately provide evidence for the use of previous research in applying flexible lane width standards to South Carolina rural highways. Through this study, it was found that the use of SCDOT's existing RIMS database as a means to develop a scope of existing conditions and sample size considerations is not feasible as it currently exists. With these and many other considerations in mind, numerous recommendations are offered regarding the ability to make informed design-related decisions in the future. These recommendations, including lessons learned and some suggested future research tasks, are discussed in Chapter 5.

5.0 Conclusions and Recommendations

The overall goal of this study was to determine the influence that flexible lane width standards could have on the safety and operation of roadways in South Carolina. Before making wholesale changes to the HDM, it was important to review prior research as well as conduct a cross-sectional analysis of existing lane width standards and safety outcomes in South Carolina. A comprehensive literature review was completed to acquire knowledge and develop a successful study methodology. A survey of state design manuals was conducted to determine state-of-the-practice with regard to variable lane and shoulder width policy adoption. An analysis of crash records, in combination with a geometric inventory of existing highways, allowed for the development of models describing the effect of lane width on crashes in South Carolina. This analysis also took into consideration the other confounding variables that affect crash rate, including paved shoulder width, speed limits, and traffic volumes. Finally, data collection at intersections allowed the study of lane width on operational parameters.

The success of the analysis process was, in many ways, dependent on the variety and consistency of roadway characteristics and the proportion of lane miles available for each of those characteristics in South Carolina. As tables 3.1, 3.2, 4.9, and 4.10 indicate, only significant sample sizes exist for a handful of site types in each of the study counties. The lack of detailed data available in RIMS, and the inconsistency of lane markings in the field only exacerbated the problems of locating suitable samples. After extensive field data collection, manual data analysis and database development, models were developed for rural two-lane undivided and four-lane divided sites, as well as urban sites including: two-lane undivided, four-lane divided and undivided, and four-lane with center TWLTL. In most cases, the resulting models mimicked what has been found nationally with regard to lane widths and safety. Past studies have found that narrower lane widths tend to increase crash rates, particularly on roads with large traffic volumes and high speeds. Almost all of the models developed solely on traffic volume were found to be significant, indicating that increased traffic volume is directly related to increased crash experience. Major findings from models for each of these road types are as follows:

However, there were some limitations noted in the models. Many of the final samples were found to be quite homogeneous in nature. For instance, the 5T (four-lane with center TWLTL) sites were made up predominantly of 12 foot lanes with only a small portion of road segments with 11 foot or 10 foot lanes. Thus, the models did not provide statistical significance for differences between 12 foot and 11 foot or 10 foot lanes – this was largely due to the small sample sizes for the lower width sites. However, this speaks volumes to the long-standing policy of requiring 12 foot lanes for this site type. When differences in crash experience between varying lane widths were found (as in the case of 10 foot lanes on rural two-lane undivided roadways), they were thought to be related to sample bias. For this site type, the sections with 10 foot lanes tended to have significantly lower speeds and traffic volumes as compared to sites with 11 and 12 foot lanes – therefore, the resulting crash experience was less. Given the noted complications in the data sample, researchers relied on the associated trends found in the data analysis and supplemented these with extensive review of prior research and popular policies in other states to help inform the recommendations for the Highway Design Manual.

The literature review and results of the model development ultimately provide evidence for the use of previous research in applying flexible lane width standards to South Carolina highways. Through this study, several safety data limitations were encountered with use of SCDOT's existing RIMS database as a means to develop a scope of existing conditions, as well as with the crash data location mapping to determine crash experience for RIMS segments. Appropriate design recommendations are provided below regarding standards for lane width on urban and suburban arterials and collectors. Further, recommendations for improvements in safety data sources (RIMS and Crash databases) are also provided with suggestions for potential future research projects.

5.1 Highway Design Manual Recommendations

Based on findings from the research and comparison with AASHTO guidelines and lane width criteria from review of other state DOT's, changes are proposed to the SCDOT Highway Design Manual (HDM). Recommendations are focused on Chapter 20, Rural Highways, and Chapter 21, Suburban/Urban Streets, however other HDM chapters that are referenced to criteria provided in these chapters would also need to be changed or modified. Proposed changes and modifications are summarized in Tables 5.1 and 5.2.

In addition to specific changes to the SCDOT HDM, shown in the accompanying tables, more generalized changes and modifications are also recommended. From the survey of states and review of national literature, other State DOT's are using innovative approaches to supplement primary criteria and to provide additional flexibility with regard to lane width guidelines. Proposed changes and modifications to the SCDOT HDM include the following additional approaches.

Identify and provide design criteria for special area designations that are in addition to commonly used rural and suburban/urban arterial and collector roadway design criteria and address numerous guidelines for lane widths, access management, parking, pedestrians, bike lanes and traffic calming. Oregon DOT uses this approach and special designations include: Special Transportation Areas (STAS), Urban Business Areas (UBAs), and Commercial Centers (CCs). These special designations are briefly summarized as follows: 1.) STA characteristics and attributes include: well-developed parallel and interconnected local roadway network, adjacent land uses that provide for compact, mixed use development, on street parking, and well-developed transit, bicycle and pedestrian facilities and design speeds from 25-30 mph, 2.) UBA characteristics and attributes include: intersections designed to address the needs of pedestrians and bicyclists, provision of transit stops, inter-parcel circulation, and design speeds generally 35 mph or greater, and 3.) CC characteristics and attributes include: Shared parking and a reduction in parking to accommodate multimodal elements where alternate modes are available, compact development patterns, accessibility by a variety of routes and modes, and integration with the local road network. These proposed changes could be included in SC HDM, Chapter 9, Basic Design Controls, and new geometric design criteria tables for special area designations would be required for Chapter 20, Design of Rural Highways and Chapter 21, Design of Suburban and Urban Streets.

Include new sections or commentary regarding complete streets, context sensitive design, road diets, traffic calming and/or project right sizing. Many state DOT's have modified their highway design procedures to include these types of guidelines that result in increased flexibility in guidelines for special areas and special project objectives. These proposed changes could be included in a number of locations of the SCDOT HDM, and a likely location to introduce links to relevant locations would be Chapter 9, Basic Design Controls.

Lastly, SCDOT HCM, Chapter 9, Basic Design Controls, could be modified to include requirements for multimodal Level of Service (LOS) analysis, when relevant. Multimodal level of service analysis, as developed in the 2010 Highway Capacity Manual, includes combined operational analysis procedures for motor vehicles, transit, bicycles, and pedestrians for the purpose of determining an overall operation of a roadway environment across multiple travel modes. This could be used as an effective approach for triggering additional flexibility for lane width criteria in evaluating highway designs for suburban and urban areas.

Table 5.1: Proposed SCDOT HDM Changes for Rural Arterials and Collectors

Functional Class	**SCDOT HDM Reference**	**Variable**	**Existing Values in HDM**	**Proposed Changes**	**Basis for proposed HDM change**
Rural Two-Lane Arterials	Fig. 20.1A	Traveled Way Width	24 ft.	22-24 ft.	Research results, AASHTO, other DOT's, Harwood et al, 2000
Rural Two-Lane Collectors	Fig. 20.1B	Traveled Way Width	22-24 ft., 11-12 ft. lanes	20-24 ft., 10-12 ft. lanes	Research results, AASHTO, other DOT's, Harwood et al, 2000
Rural Two-Lane Arterials	Fig. 20.1D, Footnote 1 (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft.	Research results, AASHTO, other DOT's, Harwood et al, 2000
Rural Two-Lane Arterials	Fig. 20.1D (HDM 13.2.5)	Aux. Lane Width	12 ft.	11-12 ft.	AASHTO, other DOT's
Rural Two-Lane Arterials	Fig. 20.1D (HDM 21.2.7)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Fattis et al, 2010
Rural Two-Lane Collectors	Fig. 20.1E, Footnote 1 (HDM 13.2.3)	Travel Lane Width	11-12 ft.	10-12 ft.	Research results, AASHTO, other DOT's, Harwood et al, 2000
Rural Two-Lane Collectors	Fig. 20.1E (HDM 13.2.5)	Aux. Lane Width	11-12 ft.	10-12 ft.	AASHTO, other DOT's
Rural Two-Lane Collectors	Fig. 20.1E (HDM 21.2.7)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
Rural Four-Lane Divided Arterial	Fig. 20.2A	Traveled Way Width	24 ft.	22-24 ft.	AASHTO, other DOT's,
Rural Four-Lane Divided Arterial	Fig. 20.2C, Footnote 1 (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft.	AASHTO, other DOT's,
Rural Four-Lane	Fig. 20.2C	Aux. Lane	12 ft.	11-12 ft.	AASHTO, other DOT's,

Divided Arterial	(HDM 13.2.5)	Width			

Table 5.2: Proposed SCDOT HDM Changes for Urban/Suburban Arterials and Collectors

Functional Class	**SCDOT HDM Reference**	**Variable**	**Existing Values in HDM**	**Proposed Changes**	**Basis for proposed HDM change**
Four-Lane Suburban/Urban Street	Fig. 21.2A	Traveled Way Width	24 ft.	22-24 ft.	Research results, AASHTO, other DOT's, Potts et al, 2007, Mbatta et al, 2012
Five-Lane Urban Street (with Shoulders)	Fig. 21.2B	Traveled Way Width	24 ft.	22-24 ft.	Research results, AASHTO, other DOT's, Potts et al, 2007, Mbatta et al, 2012
Five-Lane Urban Street (with Shoulders)	Fig. 21.2B (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
Five-Lane Urban Street (Curb and Gutter)	Fig. 21.2C	Traveled Way Width	24 ft.	22-24 ft.	Research results, AASHTO, other DOT's, Potts et al, 2007, Mbatta et al, 2012
Five-Lane Urban Street (Curb and Gutter)	Fig. 21.2C (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
Suburban/Urban Multilane Arterials	Fig. 21.3A (HDM 9.2) (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft.	Research results, AASHTO, other DOT's, Potts et al, 2007, Mbatta et al, 2012
Suburban/Urban Multilane Arterials	Fig. 21.3A (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
Suburban/Urban Collectors	Fig. 20.1E (HDM 9.2) (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft.	Research results, AASHTO, other DOT's, Potts et al, 2007, Mbatta et al, 2012
Suburban/Urban Collectors	Fig. 20.1E (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
Rural Four-Lane Divided Arterial	Fig. 20.2C, Footnote 1 (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft.	AASHTO, other DOT's,

Rural Four-Lane Divided Arterial	Fig. 20.2C (HDM 13.2.5)	Aux. Lane Width	12 ft.	11-12 ft.	AASHTO, other DOT's,

5.2 Safety Data Improvement Recommendations

5.2.1 Crash Records

The research team geocoded three years of crash data from 2007 to 2009 for use on this project with moderate success. After a significant amount of correction and manual geocoding, approximately 92-93% of the records were located. Many of the crash locations were inaccurate or unusable, which was caused by a variety issues including:

1. Some coordinates were recorded in decimal degrees rather than degrees-minutes-seconds;
2. Some coordinates were recorded with insufficient precision to geocode crashes accurately;
3. Some coordinates had longitude and latitude transposed;
4. Most of the longitude values did not include a negative sign;
5. Several crash records were missing latitude, longitude, or both;
6. Many crash records had erroneous coordinate values; and
7. Some coordinates were not in longitude and latitude format but rather in state plane coordinates (South Carolina NAD 83, with units in feet).

The problems encountered in this project mirror the issues that Sarasua, Ogle, and Geoghegan [2008] experienced with South Carolina crash records from 2004 to 2006. However, after geocoding six years of crash data, an alarming trend was noted. In each successive year, the percent of unusable records continued to increase to a maximum of 7.5% in 2009. Further, the total number and proportion of records that had to be corrected manually also went up from roughly 15% of total to 23% of total between 2004 and 2009. Analyses were conducted by county and by jurisdiction to determine if there were biases, and indeed there are. Appendix C gives jurisdiction-specific numbers for total, useable, and unusable crash location records. Several jurisdictions have significant numbers of crashes with over 40% unusable including Hardeeville, Greer, and Inman to name a few. The long-term implication of unusable crash location data is the limited ability to accurately predict crashes and identify problem areas for countermeasure implementations. Thus, the safety of the driving public in these areas is compromised at the reporting level.

The research team is aware that SCDOT began implementation of a new crash data system in 2010 that allows officers to identify crash locations on a map rather than recording complex coordinates from hand-held or in-vehicle GPS receivers. This should help significantly; however, there will be some jurisdictions that will be late adopters or may continue to use paper forms indefinitely due to budgetary reasons. For these jurisdictions, training programs should be developed to encourage proper reporting of location. Further, a new system does not necessarily mean that there will not be issues with location reporting. Systematic research should be conducted to ensure that the location data is accurate and complete. This research should focus on comparison to prior studies of crash locationing and should focus on any anomalies found in the data to target training programs to eliminate any human or machine related errors.

Given the number of jurisdictions likely continuing to use a paper version of the form in the field, a few recommendations will be repeated here. The crash report must be reformatted to make accurate and precise recording of crash locations easily understandable for reporting officers. Sarasua et al. [2008] recommended that latitude and longitude entry lines be more deliberate to ensure that coordinates are recorded with enough precision in degrees-minutes-seconds. The following suggestion was made regarding the entry lines:

Lon: __ __ º __ __ ' __ __ . __ __"

Lat: __ __ º __ __ ' __ __ . __ __"

The current crash report provides designation for the use of degrees-minutes-seconds but does not dictate spaces for entry to ensure adequate precision (22). This would greatly improve the frequency with which officers record precise coordinate information from the field. If officers and data entry operators were provided with a possible range of coordinate values that would seem reasonable for a given county, this could also greatly improve their ability to recognize and correct transposed or other erroneous entries.

Beyond the recording process in the field, many crash records become erroneous through transcription errors when manually entering records into a database. Data entry operators should be educated on some of the commonly occurring errors, such as transposing coordinates or misplacing decimals. Database filters can also be helpful tools to identify unreasonable entries, such as a coordinate with a minute or second value greater than 60.

5.2.2 RIMS Database

At the outset of this project, the SCDOT RIMS database was used as the primary means of identifying segments throughout the state that could be used in the operational and safety analyses. Several design-related aspects of this database made it difficult to consistently and accurately identify all desired information for this study. Primarily, it was important to ensure that all segments used for analysis had uniform and relatively consistent lane widths over the entire length of the segment. This proved challenging considering that individual lane width was not one of the attributes recorded in the RIMS database.

The attribute most similar to lane width that is provided for each segment is total surface width. Since the number of lanes, shoulder width, and median width are provided as well, the calculation of lane width was attempted for each segment using these values. However, observations of the resulting lane widths from these calculations revealed numerous segments with unrealistic lane widths. Many of these segments included on-street parking, bike lanes or other features that required additional pavement width beyond the standard lane. While there is no indication of on-street parking in the RIMS database, the width of the parking space is typically included in the total pavement width for segments where on-street parking is present.

Another issue was the lack of information regarding shoulders with multiple surface types. Two-lane roads were commonly found with a listed 10 feet shoulder on which only 2 feet of the shoulder was actually paved. While it is important to collect both paved and unpaved shoulder information, there should be a designation for different shoulder types in the RIMS database. Calculating individual lane width using the existing total pavement width proved difficult because accurate knowledge of paved shoulder information required manual data collection.

In addition to lane width, another emphasis of this research is the study of TWLTL widths on urban and suburban arterials and collectors. This topic is covered in detail in a thesis by Jordan [Jordan III, 2012] and again was a problematic data element in RIMS. Currently, there is no distinction in the RIMS database between bituminous medians, turn lanes, transition zones, and TWLTLs. These roadway features all serve unique purposes, yet all of them are simply classified in the database as bituminous medians. This posed a significant problem because sites had to be individually verified using video log to determine the presence or absence of a TWLTL. Additionally, the lack of sufficient information regarding auxiliary lanes made it difficult to include these lanes within the overall scope of the observational study. If medians and auxiliary lanes were categorized more accurately within the RIMS database, the understanding of field conditions would be greatly improved.

Most of the issues related to the use of RIMS for this study stem from the original intent of the data to report to FHWA on the overall lane miles and pavement surface maintained by the DOT. This is a very different performance standard than that of a design inventory with intended use by multiple departments at the DOT. Considering the movement toward performance-based safety assessment, the time is drawing near to begin migration to a database structure that will satisfy requirements across the enterprise. By collecting data elements such as individual lane widths, shoulder width and type, and presence of various auxiliary lanes and median types, the RIMS database could become a great tool for decision-making, and future geometric research could be streamlined. Appendix D provides a listing of the Model Inventory of Roadway Elements currently suggested by the Federal Highway Administration. Within that listing, the research team has presented a priority rank for each data element along with indicators for whether it is required or optional for HPMS and HSM. The highlighted data elements were those that would have been used for this analysis had they been available. Some of the highlighted elements had to be generated to enable basic analysis of lane widths for this study.

In addition to the cross-sectional elements collected in the RIMS database, it was also determined that roadway segmentation could be improved for long-term growth and success. Chapter 13 of the HSM considers a roadway segment to be a “continuous portion of a roadway with similar geometric, operational, and vehicular characteristics.” As a result, when determining proper starting and ending locations for a particular segment, the HSM analyzes segments separately “where significant changes in these characteristics are observed from one location to another.” In addition, Part C of the HSM considers roadway segments to begin at the center of an intersection and end at the center of the following intersection unless there is a change in homogeneity between the intersections [HSM, 2010]. These changes consider the beginning or end of a horizontal curve, passing lane, or center TWLTL. A change in homogeneity also includes points of vertical intersection (PVI) as well as changes in AADT, lane width, shoulder width, driveway density, roadside hazard rating, centerline rumble strip presence, on-street lighting presence, and automated speed enforcement presence [HSM, 2010]. In general, it was found that many of these factors that should warrant the creation of a new segment were not considered during the RIMS segmentation process, resulting in many non-homogeneous segments within the original observational sample. If significant considerations were made to the collection of some of the HSM attributes described above, roadways could be segmented more accurately for safety analysis using a multi-criteria segmentation approach. Knowledge of these attributes can greatly improve decision-making by targeting specific areas for improvement, and future safety studies could benefit greatly by segmenting roadways at intersections and at locations with changes in specific HSM attributes.

Ultimately SCDOT should consider a research project to synthesize best-practices for roadway inventory development to support future safety analysis and other enterprise data needs. The synthesis would cover new technologies for data collection, level of detail required for each of the data elements, and the most appropriate database structure to maintain historical information on improvements as well as keeping all items dynamically updated.

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APPENDIX A

THEMATIC COUNTY MAPS FOR SEGMENT TYPE OF SELECTED SEGMENTS

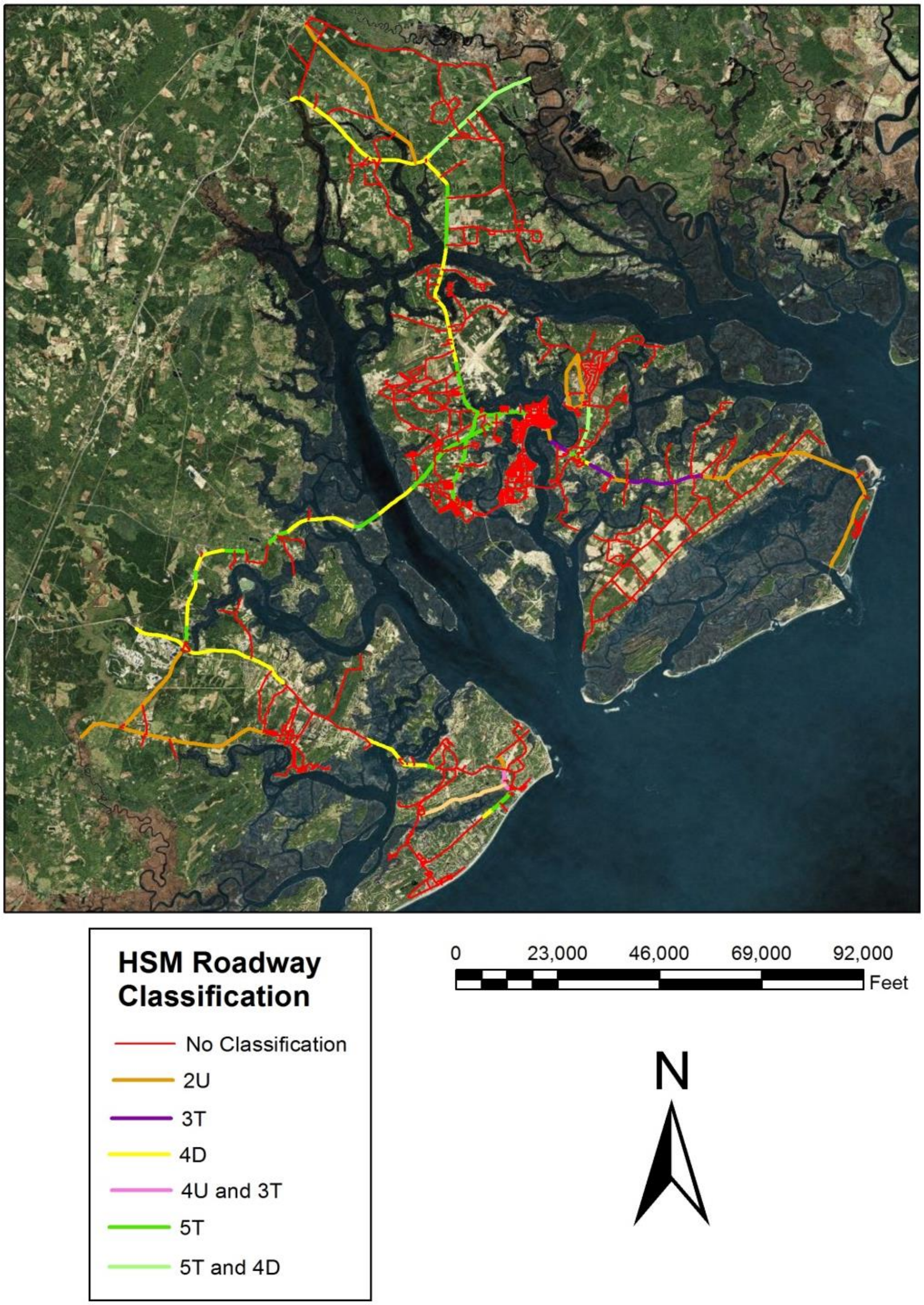


Figure A.1: HSM Roadway Classification for Selected Segments in Beaufort County

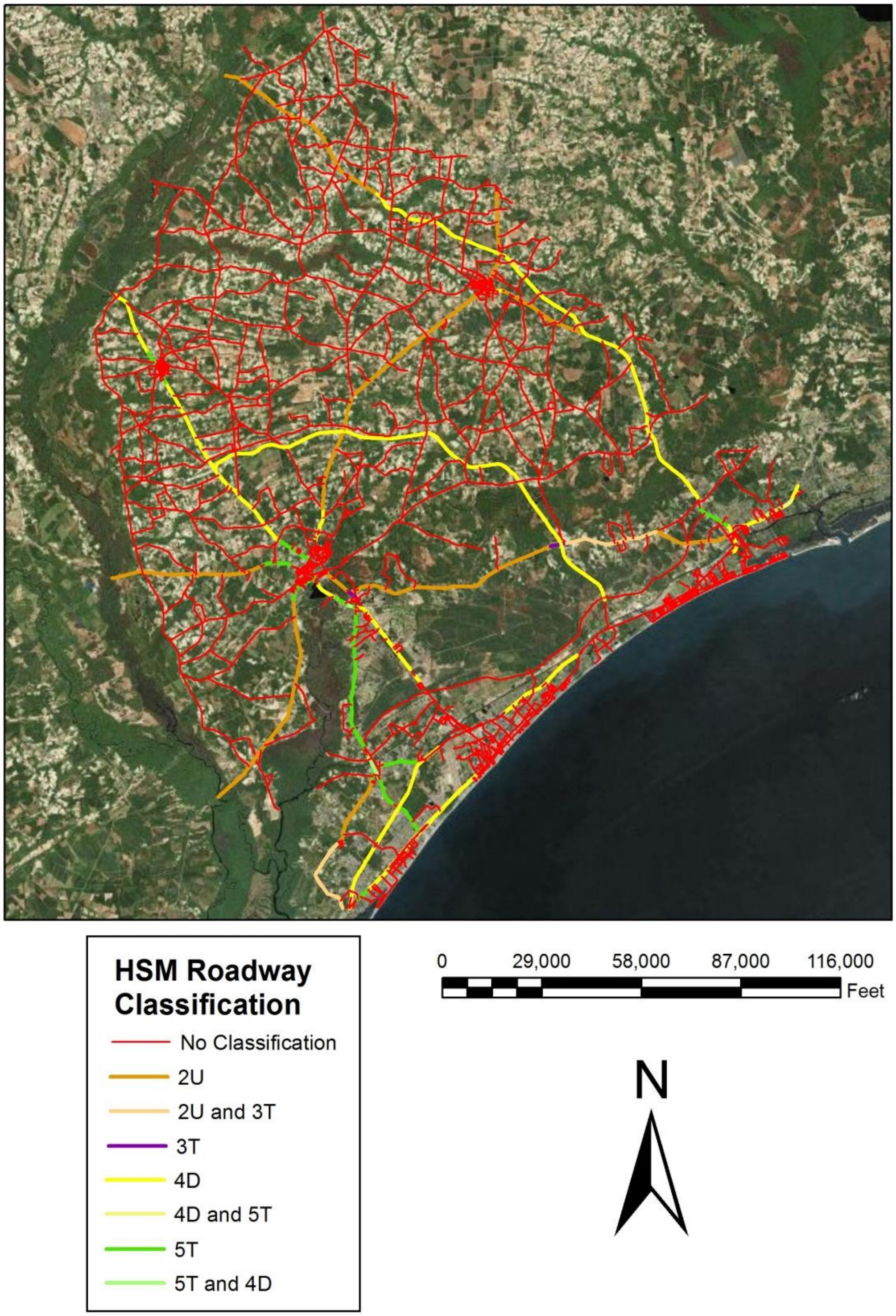


Figure A.2: HSM Roadway Classification for Selected Segments in Horry County

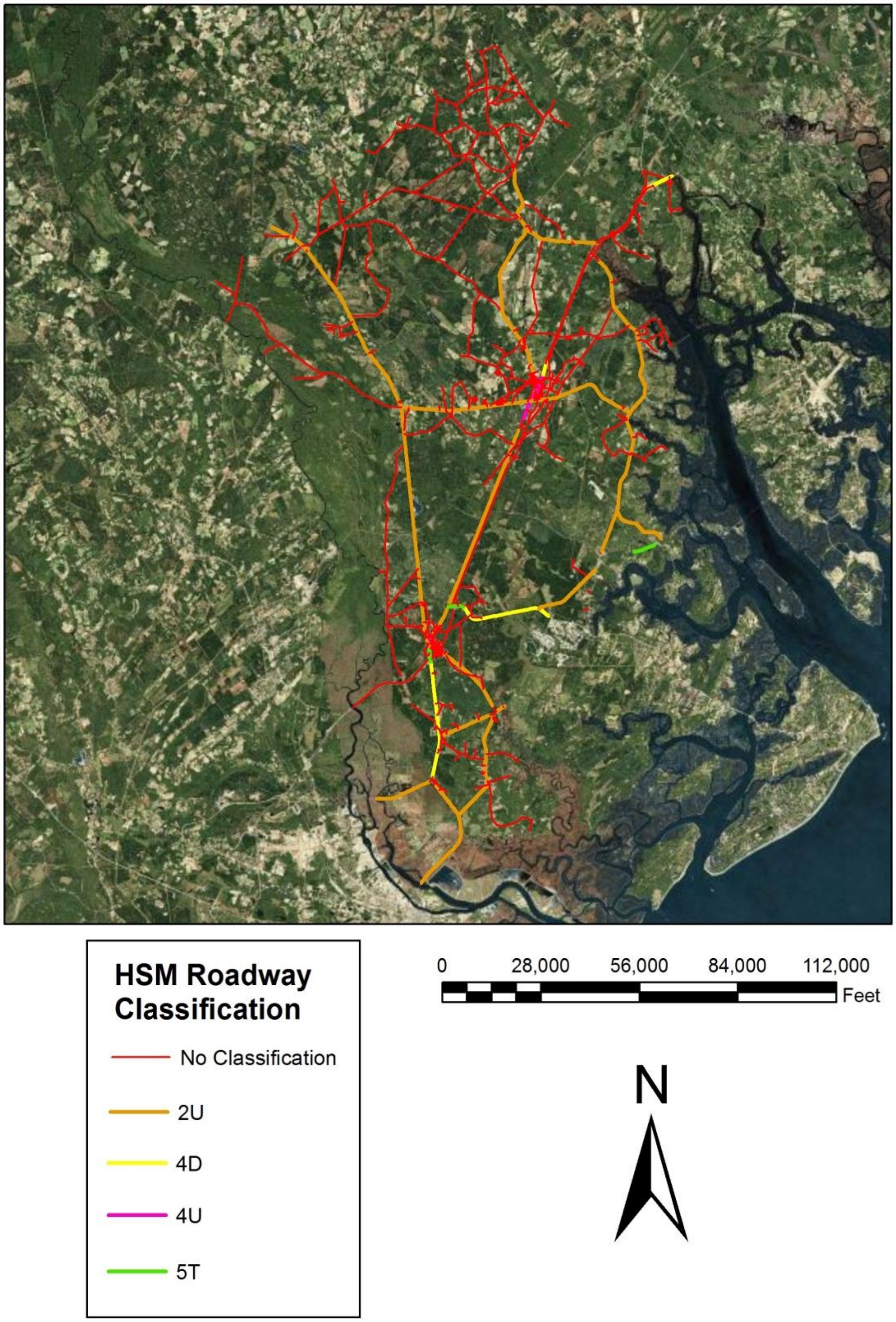


Figure A.3: HSM Roadway Classification for Selected Segments in Jasper County

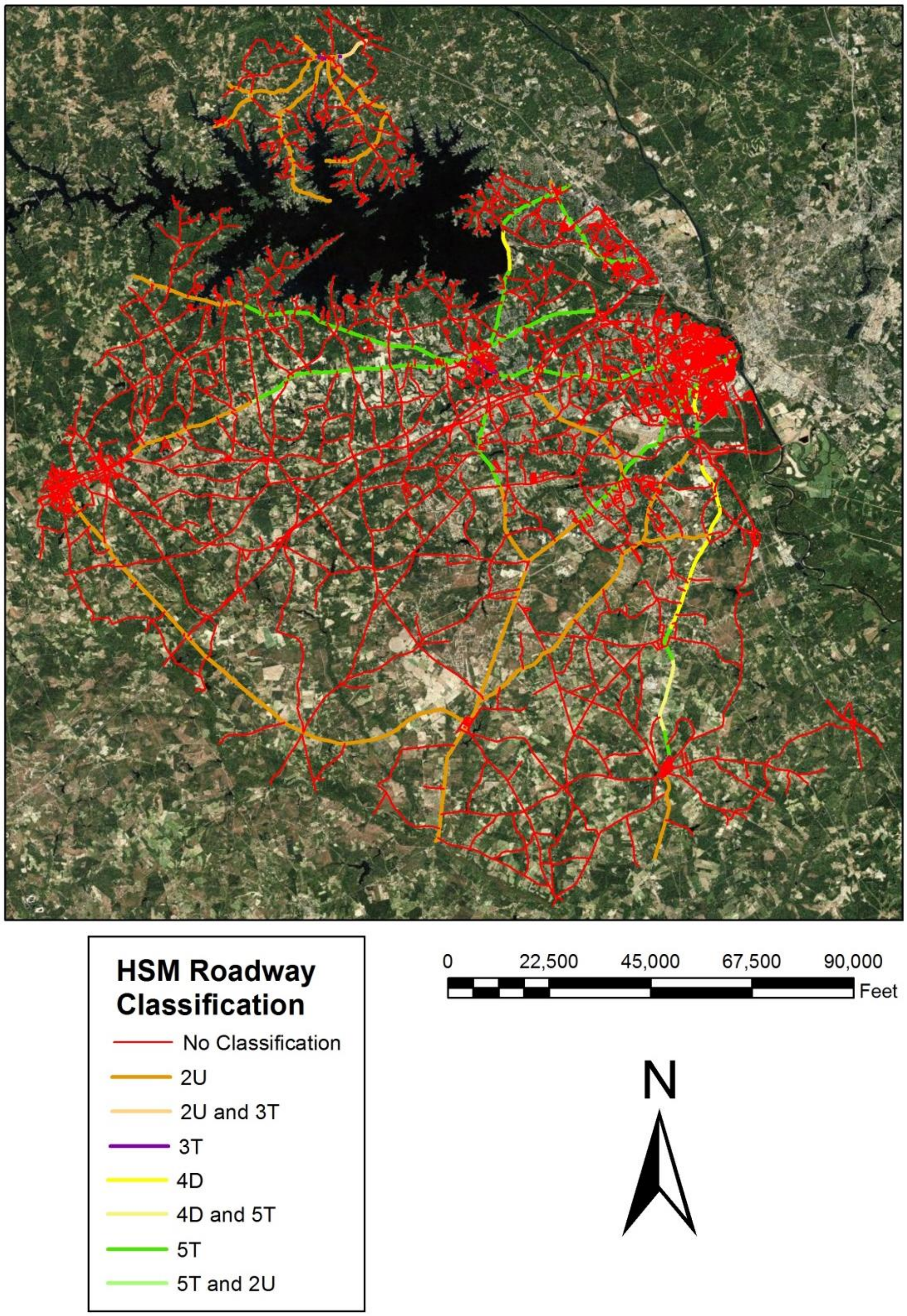


Figure A.4: HSM Roadway Classification for Selected Segments in Lexington County

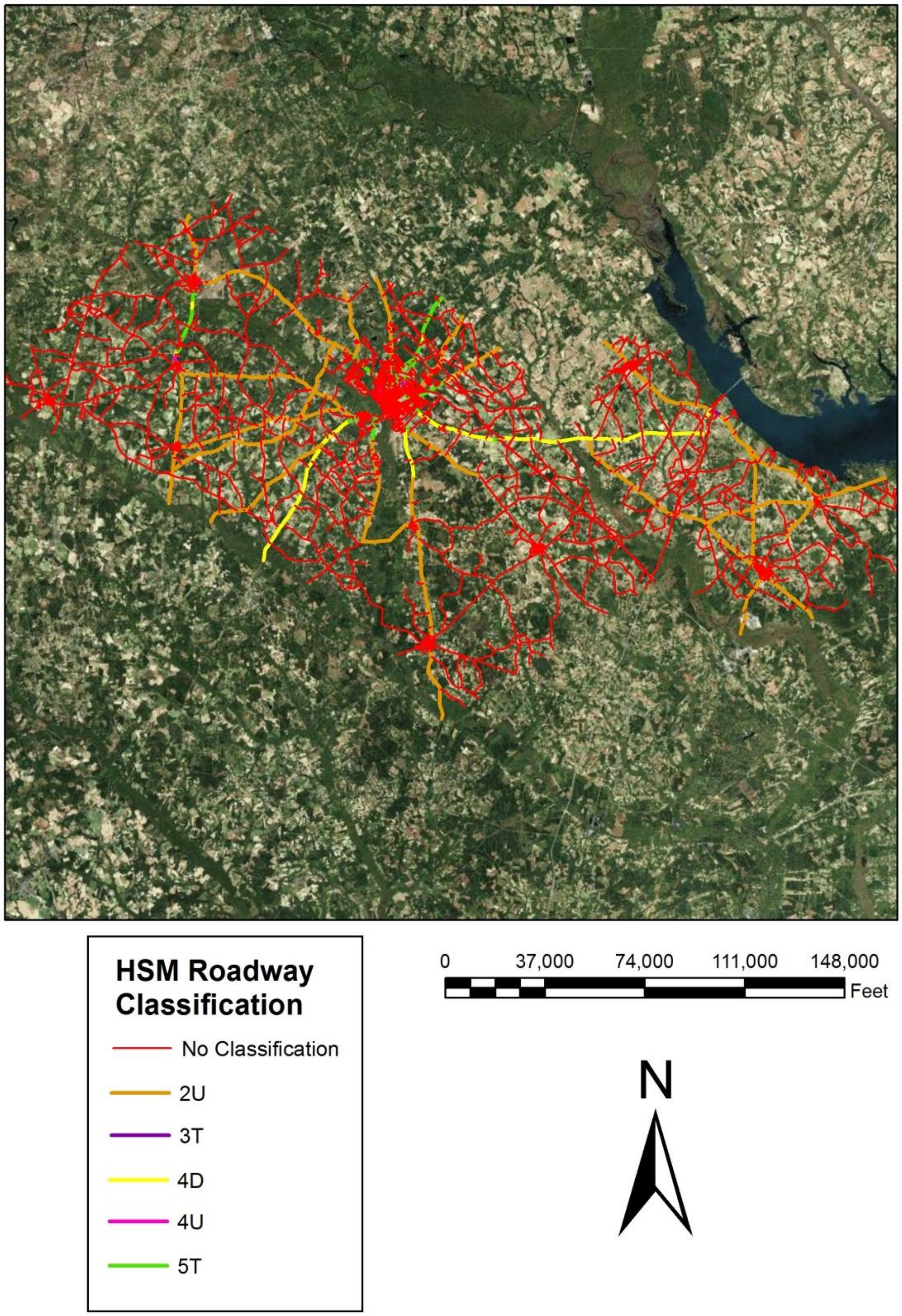


Figure A.5: HSM Roadway Classification for Selected Segments in Orangeburg County

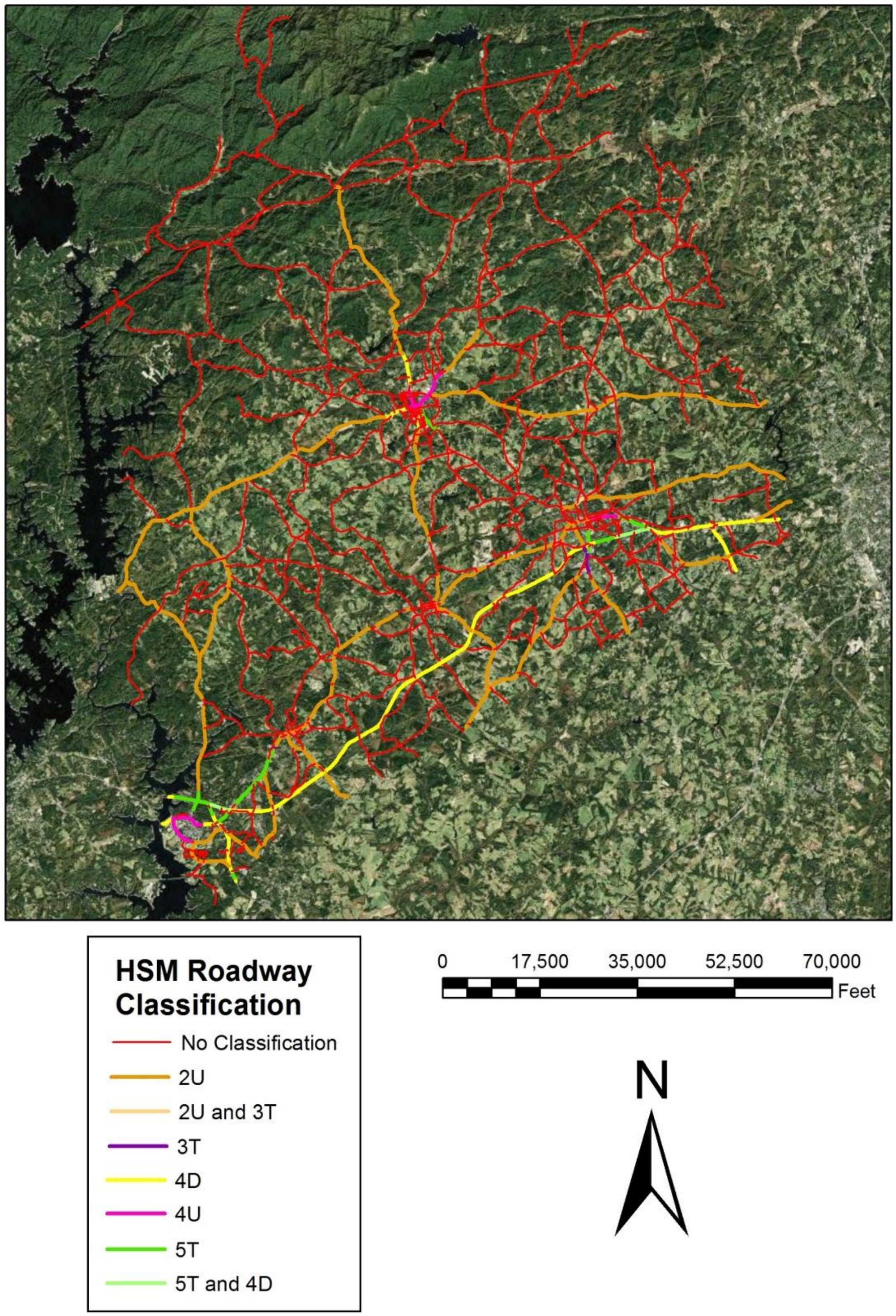


Figure A.6: HSM Roadway Classification for Selected Segments in Pickens County

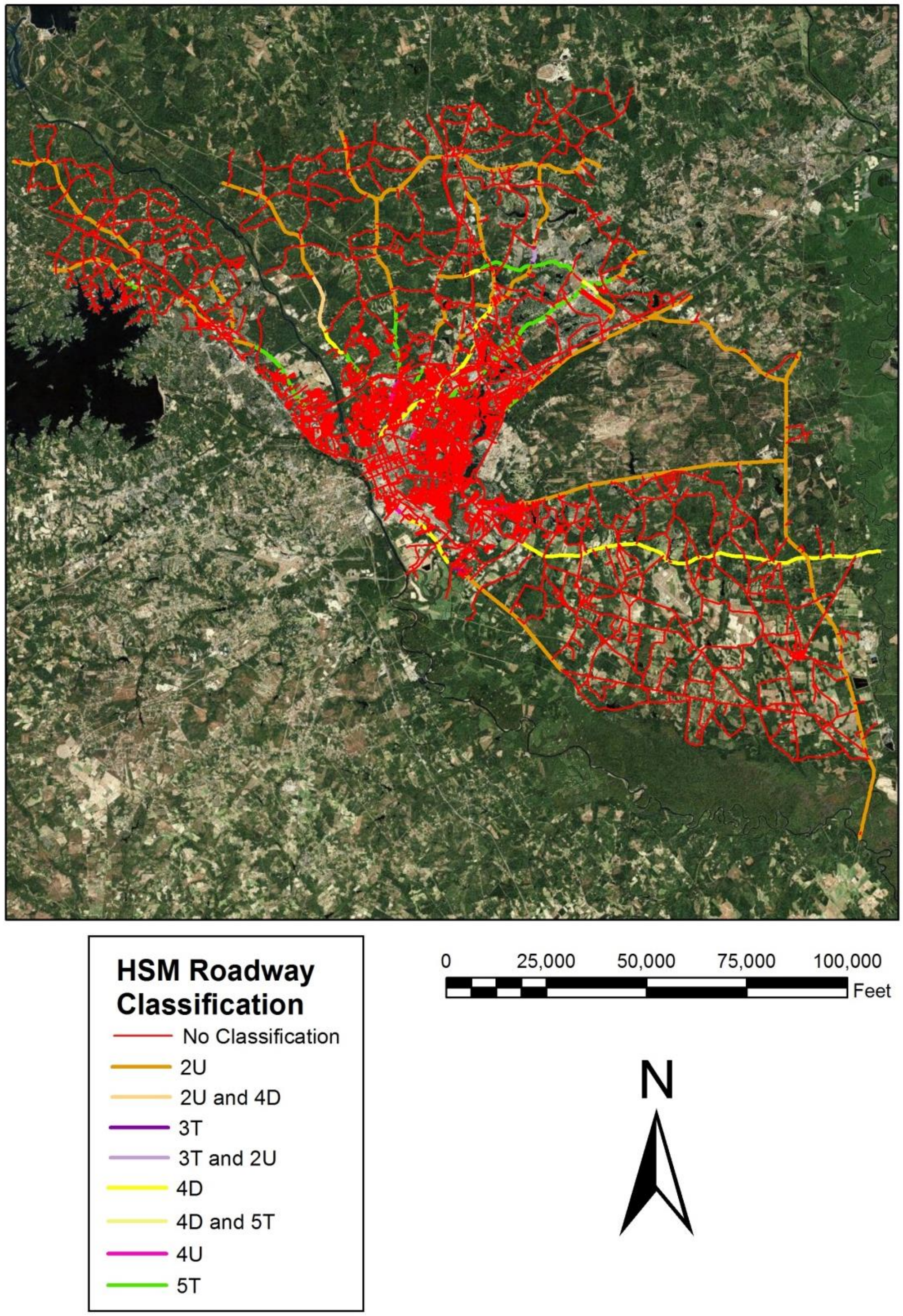


Figure A.7: HSM Roadway Classification for Selected Segments in Richland County

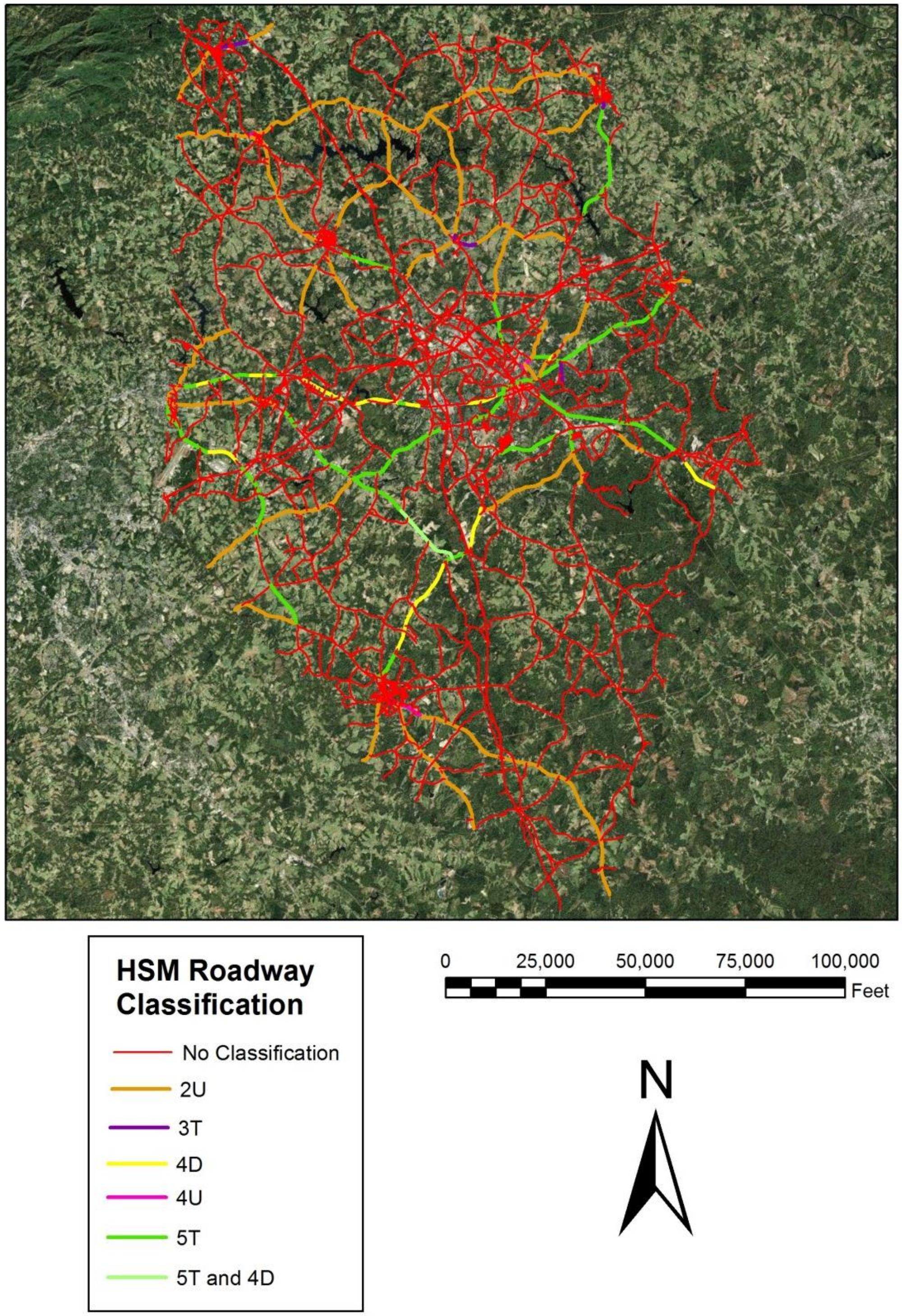
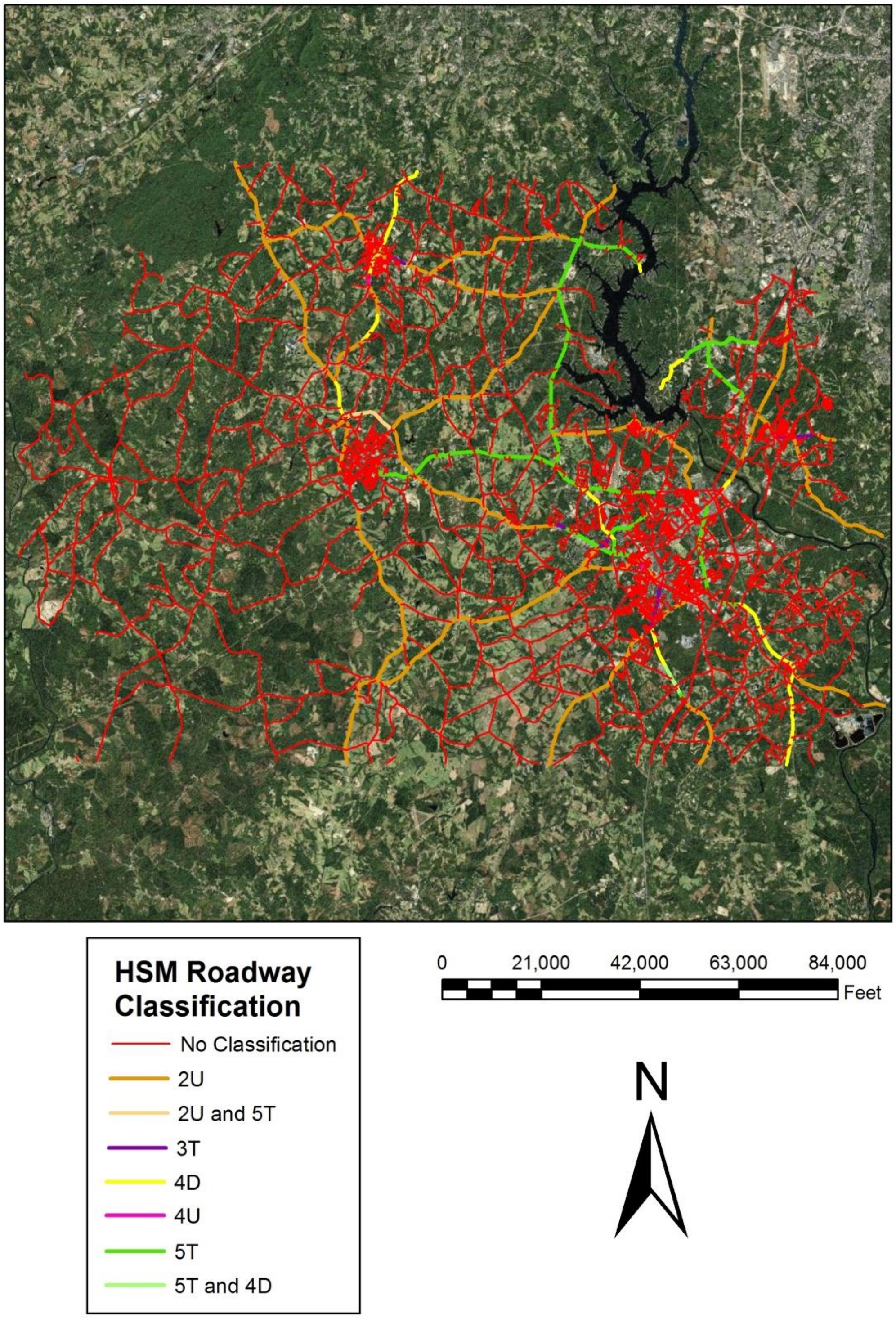


Figure A.8: HSM Roadway Classification for Selected Segments in Spartanburg County



. Figure A.9: HSM Roadway Classification for Selected Segments in York County

APPENDIX B

FINAL AGGREGATED SEGMENTS AND ATTRIBUTES USED IN MODEL DEVELOPMENT

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
1	1	2U	7	2	21	4500	3	45	12	4	N		N/A		0		Level	0.133037	0	0	0	0	0	3	22.55011764
2	1	2U	7	2	21	4700	3	55	12	2	N		N/A		0		Level	0.107851	0	0	0	0	0	0	0
3	1	2U	7	2	21	4700	3	55	12	4	N		N/A		0		Level	0.271535	0	0	0	1	1	5	18.41383247
4	2	2U	7	4	46	8800	14	55	11	4	N		N/A		2	N		0.43057	0	0	0	1	1	4	9.290010916
5	3	2U	7	7	21	2900	4	55	10	0	N		N/A		0		Level	0.683122	0	0	0	0	0	3	4.391602086
6	4	2U	7	7	21	2900	4	55	11	0	N		N/A		0		Level	1.365566	0	1	1	0	2	1	0.732297084
7	1	2U	7	7	72	8900	18	45	9	0	N		N/A		2	N		0.301271	0	0	0	0	0	2	6.63854138
8	2	2U	7	7	72	8900	18	45	10	0	N		N/A		2	N		0.524868	0	0	0	0	0	6	11.43144562
9	1	2U	7	7	406	2700	4	45	12	0	N		N/A		0		Level	0.676163	0	0	0	0	0	1	1.478933334
10	1	2U	7	7	750	3500	14	45	8	0	N		N/A		2	N		0.147142	0	0	0	0	0	0	0
11	1	2U	7	7	750	3500	14	45	9	0	N		N/A		2	N		0.153971	0	0	0	0	0	0	0
12	4	2U	26	2	378	6900	2	55	11	0	N		N/A		0		Level	1.790444	2	1	1	0	4	20	11.1704136
13	2	2U	26	2	378	6900	2	55	12	0	N		N/A		0		Level	0.591724	3	0	0	0	3	2	3.379954168
14	3	2U	26	2	501	19400	3	55	12	2	N		N/A		0		Level	0.7713	0	0	0	1	1	0	0
15	4	2U	26	2	701	7000	3	55	11	0	N		N/A		0		Level	1.34787	3	0	0	0	3	6	4.451467872
16	4	2U	26	2	701	7000	3	55	12	0	N		N/A		0		Level	1.634615	2	0	0	0	2	14	8.564707898
17	1	2U	26	2	701	7400	3	45	11	0	N		N/A		0		Level	0.118854	0	0	0	0	0	7	58.89578811
18	7	2U	26	2	701	7400	3	55	11	0	N		N/A		0		Level	2.936732	3	1	0	3	7	21	7.150805726
19	2	2U	26	2	701	7400	3	55	12	0	N		N/A		0		Level	0.28394	0	1	0	0	1	8	28.17496654
20	1	2U	26	2	701	8100	3	55	11	0	N		N/A		0		Level	0.24994	2	0	0	0	2	0	0
21	1	2U	26	2	701	8100	3	55	12	2	N		N/A		0		Level	0.163482	1	0	0	0	1	6	36.70128822
22	1	2U	26	2	701	10500	3	45	11	0	N		N/A		0		Level	0.195623	0	0	0	0	0	3	15.33562004
23	2	2U	26	2	701	10500	3	50	11	0	N		N/A		0		Level	0.718721	4	0	0	0	4	18	25.04448875
24	1	2U	26	2	701	10500	3	50	12	2	N		N/A		0		Level	0.445797	0	1	0	0	1	18	40.37712232
25	1	2U	26	2	701	10500	3	55	11	0	N		N/A		0		Level	0.403998	0	0	0	0	0	3	7.425779336
26	1	2U	26	2	701	10500	3	55	11	2	N		N/A		0		Level	0.229062	0	0	0	0	0	0	0
27	1	2U	26	2	701	12800	14	45	12	0	N	TWLTL Cat	N/A		2	N	Level	0.163044	0	0	0	0	0	7	42.93319595
28	2	2U	26	4	9	4200	2	45	11	2	N		N/A		0		Level	0.357956	0	0	0	0	0	9	25.14275498
29	1	2U	26	4	9	4200	2	45	12	2	N		N/A		0		Level	0.297682	0	0	0	0	0	6	20.15573666
30	3	2U	26	4	9	4200	2	55	11	0	N		N/A		0		Level	1.126097	0	0	0	0	0	10	8.880229678
31	2	2U	26	4	9	4200	2	55	11	2	N		N/A		0		Level	0.320554	0	0	0	0	0	5	15.59799597
32	7	2U	26	4	9	4200	2	55	12	2	N		N/A		0		Level	2.277066	2	0	0	0	2	12	5.269939475
33	1	2U	26	4	9	6800	4	45	11	0	N		N/A		0		Level	0.153889	0	0	0	0	0	3	19.49457076
34	1	2U	26	4	9	6800	4	55	11	0	N		N/A		0		Level	0.154452	1	1	0	0	2	5	32.37251703
35	3	2U	26	4	9	6800	4	55	12	0	N		N/A		0		Level	1.215108	1	0	0	0	1	20	16.45944229
36	1	2U	26	4	90	6100	3	45	12	0	N		N/A		0		Level	0.22875	0	0	0	0	0	7	30.6010929
37	5	2U	26	4	90	6100	3	45	12	2	N		N/A		0		Level	2.77301	6	1	1	1	9	42	15.14599659
38	2	2U	26	4	90	6100	3	55	12	2	N		N/A		0		Level	0.407802	1	0	0	0	1	5	12.26085208
39	3	2U	26	4	90	6700	3	45	12	2	N		N/A		0		Level	0.564573	2	2	2	0	6	23	40.738753

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
40	2	2U	26	4	90	6700	3	55	12	2	N		N/A		0		Level	0.463631	0	2	0	0	2	3	6.470663092
41	1	2U	26	4	90	7400	14	45	12	2	N		N/A		2	N	Level	0.84339	1	1	0	0	2	8	9.48552864
42	1	2U	26	4	90	10700	14	45	12	0	N		N/A		2	N	Level	0.119012	0	0	0	0	0	0	0
43	1	2U	26	4	90	10700	14	45	12	2	N		N/A		2	N	Level	0.149988	0	0	0	0	0	1	6.667200043
44	1	2U	26	4	707	18600	14	40	12	2	N		N/A		2	N	Level	0.221905	1	0	0	0	1	1	4.506432933
45	2	2U	26	4	707	18600	14	45	12	2	N		N/A		2	N	Level	0.358081	1	0	0	0	1	7	19.54864961
46	1	2U	27	2	17	2200	4	55	10	0	N		N/A		0		Level	0.302875	0	0	0	0	0	0	0
47	5	2U	27	2	17	2200	4	55	11	0	N		N/A		0		Level	3.307566	4	0	0	0	4	1	0.302337126
48	1	2U	27	2	17	2200	4	55	12	2	N		N/A		0		Level	0.351874	1	0	0	0	1	0	0
49	2	2U	27	2	17	4700	4	55	12	2	Y		N/A		0		Level	0.612386	2	0	0	0	2	0	0
50	1	2U	27	2	17	5800	2	55	11	0	N		N/A		0		Level	1.251559	3	0	0	0	3	3	2.397010449
51	2	2U	27	2	17	13100	2	55	11	2	N		N/A		0		Level	1.267655	2	1	0	0	3	0	0
52	1	2U	27	2	17	13100	2	55	12	2	N		N/A		0		Level	0.869216	3	0	0	0	3	2	2.300924051
53	3	2U	27	2	278	1600	3	55	11	0	N		N/A		0		Level	1.311139	0	0	0	0	0	0	0
54	3	2U	27	2	278	1600	3	55	12	0	N		N/A		0		Level	0.897039	1	0	0	0	1	0	0
55	1	2U	27	2	278	2900	3	45	11	0	N		N/A		0		Level	0.178593	0	0	0	0	0	0	0
56	2	2U	27	2	278	7700	3	55	12	0	N		N/A		0		Level	0.578592	0	0	0	0	0	16	27.65333776
57	2	2U	27	2	321	2800	3	55	11	0	N		N/A		0		Level	0.738085	0	0	0	0	0	2	2.709715006
58	3	2U	27	2	321	2800	3	55	12	2	N		N/A		0		Level	0.6028	0	0	0	0	0	0	0
59	1	2U	27	2	321	3700	3	55	11	0	N		N/A		0		Level	1.23307	1	0	0	1	2	0	0
60	5	2U	27	2	321	3700	3	55	12	0	N		N/A		0		Level	2.230236	3	0	1	0	4	4	1.793532164
61	3	2U	27	2	321	3900	3	55	11	0	N		N/A		0		Level	0.722311	0	0	0	0	0	7	9.69111643
62	6	2U	27	2	321	4000	3	55	11	0	N		N/A		0		Level	1.411896	3	1	0	0	4	4	2.833069858
63	3	2U	27	2	321	4000	3	55	12	0	N		N/A		0		Level	0.948042	0	0	0	0	0	2	2.109611178
64	2	2U	27	4	46	2700	4	55	11	0	N		N/A		0		Level	1.261106	2	0	0	0	2	1	0.792954756
65	1	2U	27	4	46	3400	4	45	11	0	N		N/A		0		Level	0.853998	2	0	0	0	2	8	9.367703437
66	1	2U	27	4	46	3400	4	55	11	0	N		N/A		0		Level	0.476668	0	0	0	0	0	4	8.391584919
67	2	2U	27	4	170	1700	3	45	10	0	N		N/A		0		Level	0.648387	1	0	0	0	1	12	18.50746545
68	3	2U	27	4	315	7500	4	55	12	0	N		N/A		0		Level	0.684936	1	1	0	0	2	10	14.59990422
69	1	2U	27	4	315	8000	4	55	11	0	N		N/A		0		Level	0.205144	0	0	1	0	1	8	38.99699723
70	2	2U	27	4	315	8000	4	55	12	0	N		N/A		0		Level	0.414822	1	0	0	0	1	7	16.87470771
71	1	2U	27	4	336	2000	4	55	10	0	N		N/A		0		Level	0.281218	0	0	0	0	0	8	28.44768116
72	3	2U	27	4	336	2000	4	55	12	2	N		N/A		0		Level	0.614534	0	0	0	0	0	7	11.39074486
73	1	2U	27	4	336	4100	3	55	11	0	N		N/A		0		Level	0.410924	0	0	0	0	0	0	0
74	1	2U	27	4	462	1600	4	55	11	0	N		N/A		0		Level	0.158041	0	0	0	0	0	4	25.30988794
75	1	2U	27	4	462	1950	4	55	11	0	N		N/A		0		Level	0.243509	0	0	0	0	0	1	4.106624396
76	1	2U	27	4	462	2400	4	55	12	2	N		N/A		0		Level	0.445233	1	0	0	0	1	4	8.984060031
77	1	2U	27	4	462	2600	4	55	11	4	N		N/A		0		Level	0.128934	0	0	0	0	0	0	0
78	1	2U	27	4	462	5700	3	55	12	0	N		N/A		0		Level	0.639178	2	0	0	0	2	1	1.564509417

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
79	1	2U	27	4	462	7700	3	55	11	0	N		N/A		0		Level	0.194044	1	0	0	0	1	1	5.153470347
80	4	2U	27	4	462	7700	3	55	11	2	N		N/A		0		Level	1.378364	1	0	0	0	1	1	0.725497764
81	1	2U	27	7	29	1450	15	35	9	0	N		N/A		2	N		0.120354	0	0	0	0	0	4	33.23528923
82	1	2U	27	7	29	1450	15	35	10	0	N		N/A		2	N		0.231629	0	0	0	0	0	5	21.58624352
83	1	2U	27	7	442	5684	4	45	10	0	N		N/A		0		Level	0.177202	0	0	0	0	0	0	0
84	1	2U	27	7	442	5684	4	55	10	0	N		N/A		0		Level	0.672409	0	0	0	0	0	0	0
85	2	2U	27	7	442	5684	4	55	11	0	N		N/A		0		Level	0.516166	0	0	0	0	0	5	9.686806183
86	4	2U	32	2	1	5900	3	55	12	0	N		N/A		0		Level	0.890371	1	0	0	1	2	14	15.72378256
87	1	2U	32	2	1	5900	3	55	12	0	N		N/A		0		Moderate	0.163432	1	1	0	0	2	1	6.118752753
88	3	2U	32	2	1	5900	3	55	13	0	N		N/A		0		Level	0.997558	0	0	0	0	0	31	31.07588732
89	2	2U	32	2	1	5900	3	55	13	0	N		N/A		0		Moderate	0.713335	3	0	1	0	4	9	12.61679295
90	1	2U	32	2	76	10300	3	45	11	0	N		N/A		0		Level	0.205428	0	0	0	0	0	6	29.20731351
91	1	2U	32	2	76	10300	3	45	11	0	N		N/A		0		Moderate	0.378824	0	0	0	0	0	7	18.47823792
92	5	2U	32	2	76	10300	3	55	11	0	N		N/A		0		Level	0.878322	1	0	0	0	1	9	10.24681153
93	1	2U	32	2	76	12800	3	45	11	0	N		N/A		0		Level	0.278038	0	0	0	0	0	11	39.56293744
94	1	2U	32	2	178	3000	3	55	11	0	N		N/A		0		Level	0.758823	1	0	0	0	1	6	7.906982261
95	1	2U	32	2	178	3000	3	55	11	0	N		N/A		0		Moderate	0.666798	1	0	0	1	2	9	13.49734102
96	3	2U	32	2	178	3000	3	55	11	2	N		N/A		0		Level	1.210133	2	0	0	0	2	11	9.089909952
97	3	2U	32	2	178	3000	3	55	12	0	N		N/A		0		Level	1.094183	1	0	0	0	1	16	14.62278248
98	1	2U	32	2	178	3000	3	55	12	2	N		N/A		0		Moderate	0.304576	0	0	0	0	0	7	22.98276949
99	4	2U	32	2	178	3200	3	55	11	0	N		N/A		0		Level	1.270887	0	1	0	0	1	15	11.80278026
100	1	2U	32	2	178	4400	3	45	12	0	N		N/A		0		Level	0.230901	0	0	0	0	0	2	8.661720824
101	4	2U	32	2	178	4400	3	55	11	0	N		N/A		0		Level	1.597249	2	0	0	0	2	23	14.39975858
102	2	2U	32	2	178	4400	3	55	11	0	N		N/A		0		Moderate	1.459227	2	0	0	0	2	14	9.594120723
103	2	2U	32	2	178	4500	3	55	11	0	N		N/A		0		Level	0.886897	1	0	0	0	1	16	18.04042634
104	1	2U	32	2	178	4500	3	55	11	0	N		N/A		0		Moderate	0.300338	0	0	0	0	0	2	6.659164009
105	4	2U	32	2	178	4500	3	55	12	0	N		N/A		0		Level	1.485055	2	0	0	0	2	24	16.16101761
106	2	2U	32	2	178	4500	3	55	12	0	N		N/A		0		Moderate	0.544111	0	1	0	0	1	4	7.351441158
107	1	2U	32	2	321	4300	2	45	12	2	N		N/A		0		Moderate	0.297937	1	0	0	0	1	8	26.8513142
108	1	2U	32	2	321	4300	2	55	11	0	N		N/A		0		Level	0.355175	0	0	0	0	0	0	0
109	3	2U	32	2	321	4300	2	55	11	0	N		N/A		0		Moderate	1.438936	4	1	0	0	5	21	14.59411676
110	2	2U	32	2	378	7900	2	55	12	0	N		N/A		0		Level	0.426413	4	0	0	0	4	7	16.41600983
111	1	2U	32	2	378	7900	2	55	12	0	N		N/A		0		Moderate	0.428898	1	0	1	0	2	2	4.663113374
112	2	2U	32	2	378	7900	2	55	12	2	N		N/A		0		Level	0.362172	0	0	0	0	0	4	11.04447611
113	2	2U	32	2	378	7900	2	55	12	2	N		N/A		0		Moderate	0.360587	0	0	0	0	0	1	2.77325583
114	2	2U	32	4	6	6100	4	45	12	0	N		N/A		0		Level	0.472491	1	0	0	1	2	19	40.21240616
115	6	2U	32	4	6	11600	4	55	12	2	N		N/A		0		Level	1.824652	5	0	0	0	5	26	14.24929247
116	2	2U	32	4	6	11600	4	55	12	2	N		N/A		0		Moderate	0.22366	1	0	0	0	1	0	0
117	1	2U	32	4	302	6100	3	45	10	0	N		N/A		0		Steep	0.288053	0	0	0	0	0	4	13.88633342

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
118	4	2U	32	4	302	6100	3	55	10	0	N		N/A		0		Level	1.003284	1	0	0	0	1	24	23.92144198
119	2	2U	32	4	302	6100	3	55	10	0	N		N/A		0		Moderate	1.423169	1	0	0	0	1	20	14.05314478
120	8	2U	32	4	302	9400	3	55	11	0	N		N/A		0		Level	2.274094	1	2	0	0	3	46	20.22783579
121	1	2U	32	4	302	9400	3	55	11	0	N		N/A		0		Moderate	0.653362	1	0	0	0	1	10	15.30545088
122	1	2U	32	4	302	9900	3	55	11	0	N		N/A		0		Level	0.359565	0	0	0	0	0	6	16.68682992
123	1	2U	32	4	302	10000	3	55	11	0	N		N/A		0		Level	0.653711	1	0	1	1	3	8	12.23782375
124	1	2U	32	4	302	10000	3	55	11	0	N		N/A		0		Moderate	0.368925	0	0	0	0	0	1	2.710578031
125	1	2U	32	4	302	10000	3	55	11	2	N		N/A		0		Level	0.224908	1	0	0	0	1	6	26.67757483
126	1	2U	32	7	29	1200	4	45	9	0	N		N/A		0		Moderate	0.284182	1	0	0	0	1	6	21.11323025
127	4	2U	32	7	29	3800	4	45	10	0	N		N/A		0		Level	0.722819	0	0	0	0	0	9	12.4512499
128	1	2U	32	7	29	3800	4	45	10	2	N		N/A		0		Level	0.107024	1	0	0	0	1	0	0
129	2	2U	32	7	29	3800	4	45	10	2	N		N/A		0		Moderate	0.705174	1	0	0	0	1	7	9.926628038
130	1	2U	32	7	48	12500	3	35	11	2	N		N/A		0		Level	0.202887	0	0	0	0	0	4	19.71540808
131	1	2U	32	7	51	7200	4	50	10	0	N		N/A		0		Level	0.193615	0	0	0	0	0	0	0
132	6	2U	32	7	51	7200	4	50	10	2	N		N/A		0		Level	0.895709	2	0	1	0	3	7	7.815038143
133	3	2U	32	7	51	7200	4	50	10	2	N		N/A		0		Moderate	0.46083	1	0	0	0	1	5	10.84998807
134	1	2U	32	7	51	9500	4	50	10	0	N		N/A		0		Level	0.248826	0	0	0	0	0	3	12.05661788
135	2	2U	32	7	51	9500	4	50	10	2	N		N/A		0		Level	0.275179	0	0	0	0	0	3	10.9019947
136	1	2U	32	7	73	1850	4	45	10	2	N		N/A		0		Level	0.238901	0	0	0	0	0	10	41.858343
137	2	2U	32	7	73	2700	4	45	10	2	N		N/A		0		Level	0.783093	0	0	0	0	0	26	33.20167592
138	1	2U	32	7	73	2700	4	45	10	2	N		N/A		0		Moderate	0.179836	0	0	0	0	0	1	5.5606219
139	1	2U	32	7	73	2700	4	45	11	2	N		N/A		0		Level	0.236146	2	0	0	0	2	5	21.17334192
140	11	2U	32	7	73	5500	14	45	10	2	N		N/A		2	N		3.280575	8	1	0	0	9	78	23.7763197
141	1	2U	32	7	83	7700	4	35	11	0	N		N/A		0		Moderate	0.132502	0	0	0	0	0	2	15.09411179
142	1	2U	32	7	83	7700	4	35	11	2	N		N/A		0		Level	0.19812	0	0	0	0	0	9	45.42701393
143	2	2U	32	7	83	7700	4	45	11	0	N		N/A		0		Level	0.334603	0	0	0	0	0	11	32.87477996
144	1	2U	32	7	168	5400	15	35	12	2	N		N/A		2	N		0.256004	0	0	0	0	0	9	35.15570069
145	1	2U	32	7	231	3100	4	45	10	2	N		N/A		0		Level	0.220837	1	0	0	0	1	5	22.64113351
146	2	2U	32	7	231	3100	4	45	10	2	N		N/A		0		Moderate	0.424969	0	0	0	0	0	5	11.76556408
147	3	2U	32	7	233	4100	4	45	10	0	N		N/A		0		Level	0.540394	3	0	0	0	3	6	11.10301003
148	1	2U	32	7	233	4100	4	45	10	2	N		N/A		0		Level	0.288888	2	0	0	0	2	3	10.38464734
149	2	2U	32	7	875	2600	15	40	10	0	N		N/A		2	N		0.38124	2	0	0	0	2	26	68.19851012
150	1	2U	32	7	875	2600	15	40	11	0	N		N/A		2	N		0.41449	1	0	0	0	1	30	72.37810321
151	1	2U	32	7	1149	3000	4	50	10	0	N		N/A		0		Moderate	0.117484	0	0	0	0	0	3	25.53539205
152	1	2U	32	7	1149	3000	4	50	10	2	N		N/A		0		Level	0.212615	0	0	0	0	0	0	0
153	1	2U	38	2	21	1450	3	55	11	2	N		N/A		0		Level	0.384167	2	0	0	0	2	0	0
154	3	2U	38	2	21	1450	3	55	12	2	N		N/A		0		Level	1.098758	1	0	0	0	1	1	0.910118516
155	1	2U	38	2	21	2800	3	45	12	2	N		N/A		0		Level	0.290614	0	0	0	0	0	3	10.32297136
156	5	2U	38	2	21	2800	3	55	12	2	N		N/A		0		Level	2.524978	1	0	0	0	1	11	4.356473601

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
157	1	2U	38	2	21	3400	3	45	12	2	N		N/A		0		Level	0.345954	1	0	0	0	1	8	23.12446163
158	1	2U	38	2	21	4200	3	55	12	2	N		N/A		0		Level	0.528518	1	0	0	0	1	2	3.784166291
159	1	2U	38	2	21	7800	14	45	11	0	N		N/A		2	N		0.135561	1	0	0	0	1	1	7.376752901
160	2	2U	38	2	176	2600	4	55	11	0	N		N/A		0		Level	0.925469	4	0	0	0	4	8	8.644265772
161	1	2U	38	2	176	2600	4	55	12	0	N		N/A		0		Level	0.411056	0	0	0	0	0	3	7.298275661
162	1	2U	38	2	176	2800	4	55	11	0	N		N/A		0		Level	0.447625	0	0	0	0	0	2	4.468025691
163	1	2U	38	2	176	2800	4	55	12	0	N		N/A		0		Level	0.230328	0	0	0	0	0	1	4.341634539
164	5	2U	38	2	176	2900	4	55	11	0	N		N/A		0		Level	1.310326	3	0	0	0	3	8	6.105350882
165	3	2U	38	2	176	3300	4	55	11	0	N		N/A		0		Level	0.90702	0	0	0	0	0	18	19.84520738
166	1	2U	38	2	176	3500	4	55	12	0	N		N/A		0		Level	0.753441	0	0	0	0	0	8	10.61795151
167	3	2U	38	2	176	3500	4	55	12	2	N		N/A		0		Level	1.354994	4	0	0	0	4	9	6.642095832
168	2	2U	38	2	178	3600	4	55	11	0	N		N/A		0		Level	0.750534	0	1	1	0	2	19	25.31530883
169	3	2U	38	2	178	3700	3	45	11	0	N		N/A		0		Level	0.883183	0	0	0	0	0	10	11.32268171
170	3	2U	38	2	178	4200	3	45	11	0	N		N/A		0		Level	1.04427	0	0	0	0	0	4	3.830426997
171	2	2U	38	2	178	4800	4	55	11	0	N		N/A		0		Level	0.414448	1	0	0	0	1	12	28.95417519
172	2	2U	38	2	178	4800	4	55	12	0	N		N/A		0		Level	0.623399	1	0	0	1	2	14	22.4575272
173	2	2U	38	2	178	7600	3	55	11	0	N		N/A		0		Level	0.5321	0	0	0	0	0	5	9.396729938
174	2	2U	38	2	178	7600	3	55	11	0	N		N/A		0		Moderate	0.378672	0	0	0	0	0	3	7.922423628
175	2	2U	38	2	321	3200	2	55	11	0	N		N/A		0		Level	0.522864	0	0	0	0	0	0	0
176	5	2U	38	2	321	3200	2	55	12	0	N		N/A		0		Level	1.410238	0	0	0	0	0	11	7.800101827
177	1	2U	38	2	321	3300	2	55	11	0	N		N/A		0		Level	0.430821	0	1	0	0	1	2	4.642299238
178	6	2U	38	2	321	3300	2	55	12	0	N		N/A		0		Level	1.957072	4	0	0	0	4	10	5.109674044
179	1	2U	38	2	321	4200	2	55	11	0	N		N/A		0		Level	0.373869	1	1	0	0	2	1	2.674733663
180	1	2U	38	2	321	4200	2	55	12	0	N		N/A		0		Level	0.237947	1	0	0	0	1	0	0
181	1	2U	38	2	321	4600	2	55	12	0	N		N/A		0		Moderate	0.233659	1	0	0	0	1	1	4.27974099
182	1	2U	38	2	321	5200	2	55	12	0	N		N/A		0		Level	0.477641	0	0	1	0	1	1	2.093622616
183	4	2U	38	4	4	4800	3	55	12	2	N		N/A		0		Level	1.446865	3	0	1	0	4	26	17.96988662
184	2	2U	38	4	4	5300	3	55	12	2	N		N/A		0		Level	0.425069	1	0	1	0	2	3	7.057677695
185	1	2U	38	4	4	6400	3	55	12	2	N		N/A		0		Level	0.158602	1	0	0	0	1	0	0
186	1	2U	38	4	6	3500	3	45	12	2	N		N/A		0		Level	0.212352	2	0	0	0	2	1	4.709162146
187	4	2U	38	4	6	3700	3	55	12	2	N		N/A		0		Level	1.033753	0	0	0	0	0	21	20.31433041
188	1	2U	38	4	6	4000	3	35	12	4	N		N/A		0		Level	0.248119	0	0	0	0	0	2	8.060648318
189	1	2U	38	4	6	4200	3	55	12	2	N		N/A		0		Level	0.208251	0	0	0	0	0	3	14.40569313
190	2	2U	38	4	6	4900	3	55	12	2	N		N/A		0		Level	0.426919	0	0	0	0	0	0	0
191	1	2U	38	4	6	5200	3	55	12	0	N		N/A		0		Level	0.21593	0	0	0	0	0	2	9.262260918
192	1	2U	38	4	6	5200	3	55	12	2	N		N/A		0		Level	0.126082	1	0	0	0	1	1	7.931346267
193	3	2U	38	4	33	2500	4	55	11	0	N		N/A		0		Level	1.426064	4	0	0	0	4	14	9.817231204
194	1	2U	38	4	33	2500	4	55	12	0	N		N/A		0		Level	0.611609	0	0	0	0	0	4	6.540126126
195	1	2U	38	4	45	1600	4	35	11	0	N		N/A		0		Level	0.612984	1	0	0	0	1	5	8.156819754

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
196	2	2U	38	4	45	1600	4	55	11	0	N		N/A		0		Level	0.944734	3	0	0	0	3	4	4.233996024
197	5	2U	38	4	45	1800	4	55	11	0	N		N/A		0		Level	2.043384	4	0	0	0	4	10	4.893842763
198	1	2U	38	4	70	3100	3	55	11	0	N		N/A		0		Level	0.200655	1	0	0	0	1	5	24.91839227
199	4	2U	38	4	70	3100	3	55	12	0	N		N/A		0		Level	1.313712	0	0	0	0	0	1	0.761201846
200	3	2U	38	4	310	1600	4	55	11	0	N		N/A		0		Level	0.72781	1	0	0	0	1	2	2.747969937
201	1	2U	38	4	310	2300	4	55	11	2	N		N/A		0		Level	0.45552	0	0	1	0	1	10	21.95293291
202	1	2U	38	4	310	3100	4	35	11	0	N		N/A		0		Level	0.22343	0	0	0	0	0	6	26.85404825
203	7	2U	38	4	400	1600	4	55	11	0	N		N/A		0		Level	1.761609	2	0	0	0	2	15	8.514942873
204	1	2U	38	4	400	1600	4	55	12	0	N		N/A		0		Level	0.344495	0	0	0	0	0	0	0
205	2	2U	38	4	400	1750	4	55	11	0	N		N/A		0		Level	1.315565	3	0	0	0	3	9	6.841167103
206	2	2U	38	4	453	2700	4	55	12	0	N		N/A		0		Level	0.713497	0	0	0	0	0	3	4.204642767
207	1	2U	38	4	453	2700	4	55	12	2	N		N/A		0		Level	0.163047	1	0	0	0	1	1	6.133200856
208	3	2U	38	4	453	3000	4	55	11	0	N		N/A		0		Level	0.642696	1	0	0	0	1	0	0
209	2	2U	38	7	29	700	5	55	10	0	N		N/A		0		Level	0.293523	0	0	0	0	0	7	23.84821632
210	1	2U	38	7	29	4100	15	45	11	0	N		N/A		2	N		0.161812	1	0	0	0	1	1	6.180011371
211	1	2U	38	7	39	850	4	55	10	2	N		N/A		0		Level	1.252828	1	0	0	0	1	0	0
212	5	2U	38	7	49	1200	4	55	11	2	N		N/A		0		Level	2.302666	5	1	0	0	6	14	6.079909114
213	1	2U	38	7	49	3300	4	45	11	8	N		N/A		0		Level	0.12701	1	0	0	0	1	11	86.60735375
214	2	2U	38	7	61	4300	4	55	12	2	N		N/A		0		Level	0.385846	1	0	0	0	1	3	7.775122717
215	2	2U	38	7	137	83	9	35	10	0	N		N/A		0		Level	0.502175	0	0	0	0	0	0	0
216	1	2U	38	7	137	204	9	35	10	0	N		N/A		0		Level	0.129129	0	0	0	0	0	0	0
217	2	2U	39	2	178	1950	3	45	10	0	N		N/A		0		Moderate	0.497545	0	0	0	0	0	7	14.06907918
218	1	2U	39	2	178	2600	3	50	10	0	N		N/A		0		Level	0.284032	1	0	0	0	1	3	10.56219018
219	1	2U	39	2	178	5100	3	45	11	0	N		N/A		0		Moderate	0.304398	1	0	0	0	1	4	13.14069081
220	1	2U	39	2	178	5100	3	45	12	0	N		N/A		0		Level	0.319486	0	1	0	0	1	10	31.30027607
221	1	2U	39	2	178	5400	3	55	11	0	N		N/A		0		Level	0.28081	3	0	0	0	3	1	3.561126741
222	1	2U	39	2	178	5400	3	55	12	0	N		N/A		0		Moderate	0.329672	0	0	0	0	0	4	12.13327186
223	3	2U	39	2	178	5900	14	55	11	0	N		N/A		2	N		0.602829	1	0	0	1	2	10	16.58845211
224	1	2U	39	2	178	6900	14	55	11	2	N		N/A		2	N		0.265397	0	0	0	0	0	5	18.83970052
225	2	2U	39	2	178	6900	14	55	12	2	N		N/A		2	N		0.24223	0	0	0	0	0	3	12.38492342
226	1	2U	39	2	178	7100	3	45	11	0	N		N/A		0		Moderate	0.124086	0	0	0	0	0	4	32.23570749
227	1	2U	39	4	8	3900	4	55	11	0	N		N/A		0		Moderate	0.177537	0	0	0	0	0	2	11.26525738
228	1	2U	39	4	8	4700	4	55	11	0	N		N/A		0		Level	0.170551	1	0	0	0	1	1	5.863348793
229	2	2U	39	4	8	9800	3	45	11	0	N		N/A		0		Level	0.389526	0	0	0	0	0	5	12.83611364
230	1	2U	39	4	8	9800	3	45	11	0	N		N/A		0		Moderate	0.172852	3	0	0	0	3	0	0
231	1	2U	39	4	93	4500	14	35	12	0	N		N/A		2	N		0.121093	1	0	0	0	1	3	24.77434699
232	1	2U	39	4	93	4900	14	35	11	0	N		N/A		2	Y		0.129185	0	0	0	0	0	4	30.96334714
233	2	2U	39	4	93	7500	14	55	12	0	N		N/A		2	N		0.260165	1	0	0	0	1	3	11.5311437
234	1	2U	39	4	124	9800	14	35	12	0	N		N/A		2	N		0.202013	1	0	0	0	1	3	14.85052942

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
235	2	2U	39	4	133	3300	4	55	10	0	N		N/A		0		Level	0.352311	0	0	0	0	0	0	0
236	1	2U	39	4	133	3500	4	30	11	0	N		N/A		0		Level	0.206598	0	0	0	0	0	5	24.20158956
237	1	2U	39	4	133	3500	4	50	11	0	N		N/A		0		Level	0.167615	0	0	0	0	0	1	5.966053158
238	1	2U	39	4	133	12700	14	45	11	0	N		N/A		2	N		0.118843	0	0	0	0	0	0	0
239	2	2U	39	4	135	2100	4	55	11	0	N		N/A		0		Level	0.45827	0	0	0	0	0	1	2.182119711
240	1	2U	39	4	135	2100	4	55	11	0	N		N/A		0		Moderate	0.150015	2	0	0	0	2	2	13.33200013
241	2	2U	39	4	135	3100	4	55	11	0	N		N/A		0		Level	0.38161	1	0	0	0	1	3	7.861429208
242	1	2U	39	4	135	5200	4	55	11	0	N		N/A		0		Level	0.131432	0	0	0	0	0	2	15.21699434
243	1	2U	39	4	183	3700	3	55	11	0	N		N/A		0		Level	0.201968	0	0	0	0	0	3	14.85383823
244	1	2U	39	4	183	4800	3	45	11	0	N		N/A		0		Level	0.444656	0	0	0	0	0	8	17.99143608
245	1	2U	39	4	183	4800	3	45	11	0	N		N/A		0		Moderate	0.235192	0	0	0	0	0	2	8.503690602
246	2	2U	39	4	183	4800	3	45	12	0	N		N/A		0		Level	0.515606	0	0	0	0	0	7	13.57625784
247	1	2U	39	4	183	5100	3	55	11	0	N		N/A		0		Level	0.122031	0	0	0	0	0	2	16.38927813
248	3	2U	39	4	183	5100	3	55	11	0	N		N/A		0		Moderate	0.784534	1	0	0	0	1	5	6.373210084
249	1	2U	39	4	183	5100	3	55	12	0	N		N/A		0		Moderate	0.188262	0	0	0	0	0	3	15.93523919
250	1	2U	39	4	183	5400	3	45	11	0	N		N/A		0		Moderate	0.226463	2	0	0	0	2	2	8.831464743
251	1	2U	39	4	183	5400	3	45	11	2	N		N/A		0		Level	0.210818	0	0	0	0	0	0	0
252	1	2U	39	4	183	5400	3	45	11	2	N		N/A		0		Moderate	0.238607	1	0	0	0	1	1	4.190991882
253	2	2U	39	4	183	5400	3	55	11	2	N		N/A		0		Level	0.430588	0	0	0	0	0	2	4.644811281
254	1	2U	39	4	183	5400	3	55	11	2	N		N/A		0		Moderate	0.106594	0	0	0	0	0	3	28.14417322
255	1	2U	39	4	183	5900	3	45	12	0	N		N/A		0		Moderate	0.168169	0	0	0	0	0	0	0
256	1	2U	39	4	183	5900	3	55	11	0	N		N/A		0		Level	0.123809	0	0	0	0	0	4	32.30782899
257	1	2U	39	4	183	5900	3	55	11	0	N		N/A		0		Moderate	0.306066	0	0	0	0	0	3	9.801807453
258	1	2U	39	4	183	6400	3	55	11	2	N		N/A		0		Level	0.196094	1	0	0	0	1	5	25.49797546
259	1	2U	39	4	183	7100	3	45	11	2	N		N/A		0		Level	0.157902	0	0	0	0	0	0	0
260	1	2U	39	4	183	7100	3	45	11	2	N		N/A		0		Moderate	0.167959	2	0	0	0	2	0	0
261	1	2U	39	4	183	7100	3	55	11	2	N		N/A		0		Level	0.367769	1	0	0	1	2	3	8.157294389
262	2	2U	39	4	183	10900	3	55	11	2	N		N/A		0		Moderate	0.301922	0	0	0	0	0	0	0
263	1	2U	39	7	18	3500	15	35	11	2	N		N/A		2	N		0.152666	0	0	0	0	0	4	26.20098778
264	1	2U	39	7	18	6400	4	45	11	0	N		N/A		0		Level	0.284061	3	0	0	1	4	5	17.60185312
265	1	2U	39	7	18	6400	4	45	11	0	N		N/A		0		Moderate	0.110519	0	0	0	0	0	2	18.09643591
266	1	2U	39	7	18	6400	4	45	12	0	N		N/A		0		Level	0.279388	0	0	0	0	0	3	10.73775538
267	1	2U	39	7	22	9100	15	35	11	2	N		N/A		2	N		0.296438	0	0	0	0	0	4	13.49354671
268	1	2U	39	7	30	3300	15	35	10	0	N		N/A		2	N		0.121265	0	0	0	0	0	2	16.49280501
269	1	2U	39	7	30	3500	15	35	10	0	N		N/A		2	N		0.092144	0	0	0	0	0	2	21.70515715
270	1	2U	39	7	30	4800	15	35	10	0	N		N/A		2	N		0.288837	1	0	0	0	1	4	13.84864128
271	1	2U	39	7	36	3900	4	45	10	0	N		N/A		0		Moderate	0.101501	1	0	0	0	1	0	0
272	2	2U	39	7	36	4600	4	45	10	0	N		N/A		0		Level	0.344298	1	0	0	0	1	4	11.61784268
273	1	2U	39	7	36	4900	4	45	10	0	N		N/A		0		Level	0.177939	1	0	0	0	1	5	28.09951725

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
274	1	2U	39	7	36	4900	15	45	10	0	N		N/A		2	N		0.164177	0	0	0	0	0	2	12.18197433
275	1	2U	39	7	160	1350	4	45	10	0	N		N/A		0		Moderate	0.114015	0	0	0	1	1	0	0
276	3	2U	39	7	160	2300	4	45	10	0	N		N/A		0		Level	0.440595	0	0	0	0	0	1	2.269658076
277	1	2U	39	7	160	2300	4	45	10	0	N		N/A		0		Moderate	0.123082	0	0	0	0	0	2	16.24932972
278	1	2U	39	7	221	4700	14	35	10	0	N		N/A		2	N		0.137854	0	0	0	0	0	1	7.254051388
279	1	2U	39	7	320	7700	14	45	12	2	N		N/A		2	N		0.181097	0	0	0	0	0	0	0
280	1	2U	40	2	1	10800	3	45	12	0	N		N/A		0		Level	0.233525	0	0	0	0	0	0	0
281	1	2U	40	2	76	15100	14	40	12	0	N		N/A		2	N		0.204297	0	0	0	0	0	6	29.36900689
282	1	2U	40	2	76	15100	14	45	11	0	N		N/A		2	N		0.113834	0	0	0	0	0	7	61.49305129
283	1	2U	40	2	76	20100	14	40	11	2	N		N/A		2	N		0.202289	1	0	1	0	2	6	29.66053517
284	1	2U	40	2	76	20100	14	45	11	0	N		N/A		2	N		0.297499	0	0	0	0	0	7	23.52949086
285	1	2U	40	2	76	20100	14	55	12	0	N		N/A		2	N		0.564279	1	0	0	0	1	8	14.17738388
286	7	2U	40	2	176	3900	4	55	11	0	N		N/A		0		Level	2.119044	3	1	0	0	4	18	8.49439653
287	1	2U	40	2	176	6800	4	55	11	0	N		N/A		0		Level	0.237922	0	0	0	0	0	6	25.21834887
288	1	2U	40	2	321	3300	3	55	11	0	N		N/A		0		Level	0.159841	1	0	0	0	1	1	6.256217116
289	1	2U	40	2	321	3300	3	55	11	0	N		N/A		0		Moderate	0.135185	1	0	0	0	1	0	0
290	5	2U	40	2	321	3300	3	55	12	0	N		N/A		0		Level	1.486201	5	0	0	1	6	21	14.12998646
291	2	2U	40	2	601	2800	2	45	12	2	N		N/A		0		Level	0.424907	2	0	0	0	2	0	0
292	1	2U	40	2	601	2800	2	55	12	0	N		N/A		0		Level	0.249383	1	0	0	0	1	1	4.009896424
293	1	2U	40	2	601	3900	2	55	12	2	N		N/A		0		Level	0.357205	0	0	0	0	0	9	25.19561596
294	1	2U	40	2	601	3900	2	55	12	2	N		N/A		0		Moderate	0.382564	1	0	0	0	1	1	2.61394172
295	1	2U	40	2	601	4200	2	55	11	0	N		N/A		0		Level	0.194558	0	0	0	0	0	0	0
296	2	2U	40	2	601	4200	2	55	11	0	N		N/A		0		Moderate	0.64317	0	0	0	0	0	0	0
297	1	2U	40	2	601	4200	2	55	12	0	N		N/A		0		Level	0.169619	0	0	0	0	0	0	0
298	2	2U	40	2	601	4200	2	55	12	2	N		N/A		0		Moderate	0.704847	2	0	0	0	2	1	1.418747615
299	1	2U	40	2	601	4200	2	55	12	2	N		N/A		0		Steep	0.307709	0	0	0	1	1	1	3.249823697
300	1	2U	40	2	601	4200	2	55	13	0	N		N/A		0		Moderate	0.349886	1	0	0	0	1	4	11.43229509
301	2	2U	40	2	601	4200	2	55	13	2	N		N/A		0		Moderate	1.185799	0	0	0	0	0	5	4.216566214
302	1	2U	40	4	12	11000	14	45	12	2	N		N/A		2	N		0.254401	1	0	0	0	1	6	23.58481295
303	3	2U	40	4	12	11000	14	55	12	2	N		N/A		2	N		0.634311	4	0	0	0	4	8	12.61210983
304	1	2U	40	4	12	14900	14	45	12	2	N		N/A		2	N		0.179748	1	0	0	0	1	4	22.25337695
305	5	2U	40	4	48	4100	3	55	11	0	N		N/A		0		Level	2.008812	4	0	0	0	4	9	4.480259975
306	1	2U	40	4	48	4100	3	55	12	0	N		N/A		0		Level	0.15297	0	0	0	0	0	0	0
307	1	2U	40	4	48	6400	3	55	11	0	N		N/A		0		Level	1.367837	2	0	0	1	3	2	1.462162524
308	1	2U	40	4	48	9600	13	55	11	0	N		N/A		2	N		0.354737	0	0	0	0	0	1	2.818989843
309	1	2U	40	4	60	5400	14	45	11	0	N		N/A		2	N		0.150067	1	0	0	0	1	0	0
310	3	2U	40	4	215	1800	3	55	11	0	N		N/A		0		Level	0.869696	1	0	0	0	1	6	6.898962396
311	2	2U	40	4	215	1800	3	55	11	0	N		N/A		0		Moderate	0.946078	3	0	0	0	3	5	5.284976503
312	1	2U	40	4	215	1800	3	55	12	0	N		N/A		0		Level	0.220997	0	0	0	0	0	6	27.14968981

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
313	8	2U	40	4	215	3200	3	55	12	0	N		N/A		0		Level	2.344227	6	0	0	0	6	13	5.545538039
314	2	2U	40	4	262	1550	15	55	11	0	N		N/A		2	N		1.888535	3	0	0	0	3	20	10.5902194
315	2	2U	40	4	262	7300	15	55	11	0	N		N/A		2	N		2.402633	6	0	0	0	6	28	11.65388139
316	4	2U	40	4	262	7300	15	55	12	0	N		N/A		2	N		4.315967	3	0	0	1	4	42	9.731307028
317	2	2U	40	4	555	7700	4	50	11	0	N		N/A		0		Level	0.604962	2	0	1	0	3	27	44.63090244
318	1	2U	40	4	555	9600	14	50	11	0	N		N/A		2	N		0.229358	1	0	0	0	1	0	0
319	1	2U	40	7	52	11600	3	45	10	0	N		N/A		0		Level	0.206281	1	0	0	0	1	5	24.23878108
320	1	2U	40	7	52	11600	3	45	10	0	N		N/A		0		Moderate	0.307614	0	0	0	0	0	3	9.752482007
321	3	2U	40	7	52	19100	14	45	12	2	N		N/A		2	N		0.505037	2	0	0	0	2	6	11.88031768
322	4	2U	40	7	54	4500	4	40	11	0	N		N/A		0		Level	0.844421	1	0	0	0	1	5	5.921217023
323	1	2U	40	7	54	4500	4	40	11	0	N		N/A		0		Moderate	0.192083	0	0	0	0	0	3	15.61824836
324	3	2U	40	7	54	4500	4	40	11	2	N		N/A		0		Level	0.479988	0	0	0	0	0	8	16.66708334
325	2	2U	40	7	54	4500	4	55	11	2	N		N/A		0		Level	0.705086	0	0	0	0	0	15	21.27400062
326	3	2U	40	7	83	4200	4	45	10	2	N		N/A		0		Level	0.475101	0	0	0	0	0	3	6.314446823
327	1	2U	40	7	83	4200	4	45	10	2	N		N/A		0		Moderate	0.561853	0	0	0	0	0	6	10.67894983
328	2	2U	40	7	83	16200	14	45	11	2	N		N/A		2	N		0.551778	2	1	1	0	4	20	36.24646144
329	1	2U	40	7	83	19600	14	45	10	2	N		N/A		2	N		0.193928	0	0	0	0	0	0	0
330	1	2U	40	7	268	3500	15	45	11	2	N		N/A		2	N		0.302009	3	0	0	0	3	2	6.622319202
331	4	2U	40	7	268	3500	15	55	11	2	N		N/A		2	N		0.959272	0	0	0	0	0	5	5.212285984
332	1	2U	40	7	268	3500	15	55	11	4	N		N/A		2	N		0.21586	0	0	0	0	0	2	9.265264523
333	1	2U	40	7	268	5900	15	55	11	2	N		N/A		2	N		0.903254	1	0	0	0	1	2	2.214216599
334	1	2U	40	7	268	5900	15	55	11	4	N		N/A		2	N		0.522939	0	0	0	0	0	0	0
335	5	2U	40	7	2200	2700	4	55	10	2	N		N/A		0		Level	0.857729	0	0	0	0	0	16	18.6539105
336	1	2U	42	2	176	5600	4	45	11	0	N		N/A		0		Level	0.400692	0	0	0	0	0	6	14.97409482
337	1	2U	42	2	176	9500	4	45	11	0	N		N/A		0		Level	0.345764	0	0	0	0	0	4	11.56858435
338	1	2U	42	2	221	4900	4	55	11	0	N		N/A		0		Level	0.210924	0	0	0	0	0	0	0
339	1	2U	42	4	11	2700	3	55	12	0	N		N/A		0		Level	0.15383	0	0	0	0	0	0	0
340	1	2U	42	4	11	3200	3	35	12	0	N		N/A		0		Level	0.133173	0	0	0	0	0	1	7.509029608
341	1	2U	42	4	11	3200	3	55	12	0	N		N/A		0		Moderate	0.269504	0	0	0	0	0	3	11.1315602
342	1	2U	42	4	11	3300	3	45	12	0	N		N/A		0		Level	0.18158	0	0	0	0	0	4	22.0288578
343	1	2U	42	4	11	3300	3	55	11	0	N		N/A		0		Level	0.231428	0	0	0	0	0	4	17.28399329
344	2	2U	42	4	11	3300	3	55	12	0	N		N/A		0		Level	0.569269	0	0	1	0	1	12	21.07966533
345	2	2U	42	4	11	4100	3	55	11	0	N		N/A		0		Level	0.464355	1	0	0	0	1	6	12.92114869
346	1	2U	42	4	56	1150	4	55	10	0	N		N/A		0		Level	0.279474	0	0	0	0	0	1	3.578150383
347	1	2U	42	4	56	3700	3	45	11	0	N		N/A		0		Level	0.337507	1	0	0	1	2	5	14.81450755
348	1	2U	42	4	101	2700	4	45	10	0	N		N/A		0		Level	0.360542	1	0	0	0	1	6	16.6416118
349	4	2U	42	4	146	2600	4	55	11	0	N		N/A		0		Level	1.289378	1	0	0	0	1	13	10.08238081
350	5	2U	42	4	146	4600	4	55	11	0	N		N/A		0		Level	1.643034	0	1	0	0	1	20	12.17260264
351	2	2U	42	4	146	4600	4	55	12	0	N		N/A		0		Level	0.658802	2	0	0	0	2	2	3.035813492

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
352	1	2U	42	4	292	6800	3	55	11	0	N		N/A		0		Level	0.186617	0	0	0	0	0	0	0
353	1	2U	42	4	292	6800	3	55	11	0	N		N/A		0		Moderate	0.344686	0	0	0	0	0	1	2.901191229
354	1	2U	42	4	296	4000	4	45	10	0	N		N/A		0		Level	0.272054	1	0	0	0	1	4	14.70296338
355	1	2U	42	4	296	6200	4	45	10	0	N		N/A		0		Level	0.154042	0	0	0	0	0	0	0
356	1	2U	42	4	296	6200	4	45	12	2	N		N/A		0		Level	0.141626	0	0	0	0	0	1	7.060850409
357	1	2U	42	4	357	5500	14	45	9	0	N		N/A		2	N		0.193304	0	0	0	0	0	11	56.90518561
358	1	2U	42	4	357	5500	14	45	10	0	N		N/A		2	N		0.214364	0	0	0	1	1	11	51.3145864
359	2	2U	42	7	40	5100	14	40	10	0	N		N/A		2	N		0.477228	0	0	0	0	0	9	18.85891021
360	1	2U	42	7	43	7500	15	35	11	0	N		N/A		2	N		0.128915	0	0	0	0	0	7	54.29934453
361	1	2U	42	7	56	1600	4	45	9	2	N		N/A		0		Level	0.194346	0	0	0	0	0	5	25.72731108
362	1	2U	42	7	56	1600	4	45	10	2	N		N/A		0		Level	0.211336	0	0	1	0	1	5	23.65900746
363	3	2U	42	7	88	2700	15	45	11	0	N		N/A		2	N		0.728282	2	0	0	0	2	11	15.10403937
364	1	2U	42	7	128	4510	9	35	10	0	N		N/A		0		Level	0.344697	0	0	0	0	0	2	5.802197292
365	1	2U	42	7	192	2100	15	35	9	0	N		N/A		2	N		0.184054	1	0	0	0	1	10	54.33188086
366	1	2U	46	2	21	6600	14	35	12	8	N		N/A		2	N		0.971734	1	1	0	0	2	0	0
367	3	2U	46	2	21	6600	14	45	12	6	N		N/A		2	N		0.772303	0	0	0	0	0	3	3.884485752
368	1	2U	46	2	21	7900	13	55	12	6	N		N/A		2	N		0.209209	0	0	0	0	0	0	0
369	1	2U	46	2	321	3100	3	35	13	2	N		N/A		0		Level	0.176982	0	0	0	0	0	2	11.30058424
370	1	2U	46	2	321	3100	3	55	12	2	N		N/A		0		Moderate	0.309671	0	0	0	0	0	0	0
371	2	2U	46	2	321	3400	3	55	12	2	N		N/A		0		Level	0.67908	1	0	0	1	2	7	10.30806385
372	3	2U	46	2	321	5200	13	45	12	0	N		N/A		2	N		0.802127	1	1	1	0	3	8	9.973483002
373	2	2U	46	2	321	5300	3	55	12	2	N		N/A		0		Level	0.74861	0	0	0	0	0	21	28.05198969
374	3	2U	46	4	5	9800	2	45	12	4	N		N/A		0		Moderate	0.854681	0	0	0	0	0	17	19.89046206
375	1	2U	46	4	5	9800	2	55	11	0	N		N/A		0		Level	0.113225	0	0	0	0	0	1	8.831971738
376	1	2U	46	4	5	9800	2	55	11	0	N		N/A		0		Moderate	0.223887	0	0	0	0	0	5	22.33269462
377	1	2U	46	4	5	11400	2	45	12	0	N		N/A		0		Level	0.26122	0	0	0	0	0	8	30.62552638
378	1	2U	46	4	5	11400	2	55	12	0	N		N/A		0		Level	0.356053	2	0	0	0	2	4	11.23428254
379	4	2U	46	4	49	5300	3	55	11	0	N		N/A		0		Level	1.388697	2	0	0	0	2	11	7.921094378
380	3	2U	46	4	49	5700	3	55	11	0	N		N/A		0		Level	0.502139	1	0	0	0	1	7	13.94036313
381	4	2U	46	4	49	5700	3	55	11	0	N		N/A		0		Moderate	0.951339	1	0	0	0	1	7	7.358050075
382	1	2U	46	4	49	5800	3	55	10	0	N		N/A		0		Moderate	0.27039	0	0	0	0	0	7	25.88853138
383	2	2U	46	4	49	5800	3	55	11	0	N		N/A		0		Level	0.791258	0	0	0	0	0	13	16.42953373
384	1	2U	46	4	55	3900	3	55	12	0	N		N/A		0		Level	0.190669	0	0	0	0	0	2	10.48938212
385	4	2U	46	4	55	3900	3	55	12	2	N		N/A		0		Level	1.633357	0	0	0	1	1	16	9.795776429
386	1	2U	46	4	55	3900	3	55	12	2	N		N/A		0		Moderate	0.33347	0	0	0	0	0	6	17.99262302
387	2	2U	46	4	55	4900	4	45	11	0	N		N/A		0		Level	0.29474	0	0	0	0	0	1	3.392820791
388	1	2U	46	4	55	4900	4	45	11	0	N		N/A		0		Moderate	0.189025	0	0	0	0	0	3	15.87091655
389	3	2U	46	4	55	4900	4	45	11	2	N		N/A		0		Level	0.475778	0	0	0	0	0	2	4.203641194
390	3	2U	46	4	72	6000	3	55	12	2	N		N/A		0		Level	0.662123	5	0	0	0	5	17	25.67498788

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
391	2	2U	46	4	72	6000	3	55	12	2	N		N/A		0		Moderate	0.808104	6	0	0	0	6	15	18.56196727
392	1	2U	46	4	72	9900	13	55	11	0	N		N/A		2	N		0.19709	0	0	0	0	0	0	0
393	1	2U	46	4	160	11300	13	45	12	2	N		N/A		2	N		0.112974	0	0	0	0	0	2	17.70318834
394	1	2U	46	4	160	14800	13	45	11	0	N		N/A		2	N		0.147392	0	1	0	0	1	10	67.84628745
395	1	2U	46	4	160	19400	13	45	11	2	N		N/A		2	N		0.184764	0	0	0	0	0	0	0
396	3	2U	46	4	161	3400	3	55	11	0	N		N/A		0		Level	0.876596	1	0	0	0	1	18	20.5339746
397	1	2U	46	4	161	3400	3	55	11	0	N		N/A		0		Moderate	0.222112	1	0	0	0	1	1	4.502233108
398	1	2U	46	4	161	3900	3	55	11	0	N		N/A		0		Level	0.297779	0	0	0	0	0	4	13.43278069
399	1	2U	46	4	322	4700	4	35	11	2	N		N/A		0		Level	0.116572	0	0	0	0	0	5	42.89194661
400	2	2U	46	4	322	4700	4	55	11	2	N		N/A		0		Moderate	0.704152	0	0	0	0	0	9	12.7813313
401	3	2U	46	4	322	4700	4	55	11	2	N		N/A		0		Steep	1.167157	2	0	0	0	2	8	6.854262109
402	1	2U	46	4	557	7600	3	45	11	2	N		N/A		0		Level	0.139	0	0	0	0	0	5	35.97122302
403	1	2U	46	4	557	7600	3	45	11	2	N		N/A		0		Moderate	0.189192	0	0	0	0	0	1	5.285635756
404	2	2U	46	4	557	7600	3	50	11	2	N		N/A		0		Level	0.378453	1	0	0	0	1	11	29.0656964
405	2	2U	46	4	557	7600	3	50	11	2	N		N/A		0		Moderate	0.868728	2	1	0	1	4	1	1.151108287
406	1	2U	46	4	557	7600	3	55	11	2	N		N/A		0		Level	0.398713	0	0	0	0	0	2	5.016139429
407	1	2U	46	4	557	7600	3	55	12	0	N		N/A		0		Level	0.117341	0	0	0	0	0	0	0
408	2	2U	46	7	36	7400	4	45	10	2	N		N/A		0		Level	0.41723	1	0	0	0	1	0	0
409	1	2U	46	7	177	5400	4	45	10	0	N		N/A		0		Level	0.140646	1	0	0	0	1	2	14.22009869
410	3	2U	46	7	195	5400	14	45	11	0	N		N/A		2	N		0.707764	1	0	0	0	1	9	12.71610311
411	1	2U	46	7	195	9100	14	35	10	0	N		N/A		2	N		0.152112	0	0	0	0	0	6	39.44461975
412	2	2U	46	7	195	9100	14	45	10	0	N		N/A		2	N		0.36305	4	0	0	1	5	13	35.80773998
413	1	2U	46	7	561	4816	15	35	10	0	N		N/A		2	N		0.247811	0	0	0	0	0	9	36.31800041
414	1	3T	7	2	21	9600	3	45	14	4	N	T	10		2	Y		0.553069	0	0	0	0	0	9	16.27283395
415	1	3T	7	2	21	14800	14	40	12	4	N	T	17		2	Y		0.234781	0	1	0	0	1	0	0
416	1	3T	7	2	21	15100	3	35	14	4	N	T	10		2	N		1.361335	0	4	0	0	4	15	11.01859572
417	1	3T	7	2	21	15100	3	35	14	6	N	T	10		2	Y		0.172899	0	0	0	0	0	6	34.70234067
418	1	3T	7	2	21	17400	14	40	12	4	N	T	16		2	Y		0.208432	0	0	0	0	0	7	33.58409457
419	1	3T	7	2	21	18300	14	50	12	4	N	T	15		2	Y		0.789973	0	1	0	0	1	11	13.92452653
420	1	3T	26	2	501	19400	3	40	11	0	N	T	17		2	N		0.244597	1	0	1	0	2	11	44.97193343
421	1	3T	26	4	90	6100	3	45	11	0	N	T	15		2	N		0.172611	1	0	0	0	1	0	0
422	1	3T	26	4	90	6700	3	45	11	0	N	T	14		2	N		0.222611	0	0	0	0	0	6	26.952846
423	2	3T	32	2	1	16800	13	35	13	0	N	T	10		4	Y		0.344841	0	0	3	0	3	23	66.69740547
424	1	3T	32	2	1	25400	13	35	12	0	N	T	11		2	Y		0.174018	0	2	0	0	2	13	74.70491558
425	1	3T	32	2	1	25400	13	35	12	0	N	T	11		4	Y		0.139994	0	1	0	0	1	6	42.85897967
426	1	3T	32	2	76	12800	3	35	12	0	N	T	12		2	Y		0.119938	0	0	0	0	0	10	83.37641115
427	1	3T	32	2	321	9250	2	35	13	0	N	T	13		2	Y		0.250511	0	1	0	1	2	13	51.89392881
428	1	3T	32	2	321	10300	2	35	14	0	N	T	13		2	Y		0.256502	0	0	0	0	0	19	74.0734965
429	2	3T	38	4	6	7000	3	35	10	2	Y	T	12		2	N		0.262971	0	0	0	0	0	24	91.26481627

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
430	1	3T	39	4	8	7400	13	35	-1	0	N	T	12		2	Y		0.117004	0	0	1	0	1	4	34.18686541
431	1	3T	39	4	8	9700	13	35	12	0	N	T	12		2	Y		0.15553	0	0	0	0	0	5	32.14813862
432	1	3T	39	4	8	15400	13	35	-1	0	N	T	13		2	Y		0.072973	0	0	0	0	0	2	27.40739726
433	1	3T	39	4	8	15400	13	35	-1	0	N	T	15		2	Y		0.072702	1	0	0	0	1	2	27.50955957
434	1	3T	39	4	93	18000	14	35	12	2	Y	T	10		2	Y		0.156193	0	0	0	0	0	6	38.41401343
435	1	3T	39	7	21	7500	14	35	13	4	Y	T	11		2	N		0.103003	0	0	0	0	0	6	58.25073056
436	1	3T	40	7	83	23800	14	45	11	2	N	T	12		2	N		0.180997	0	0	0	0	0	5	27.62476726
437	1	3T	42	4	14	10600	14	35	12	0	N	T	10		2	Y		0.172008	0	1	0	0	1	12	69.76419701
438	1	3T	42	4	14	10600	14	35	12	0	N	T	14		2	Y		0.104428	0	0	0	1	1	2	19.15195158
439	1	3T	42	4	14	10600	14	35	12	0	Y	T	16		2	Y		0.154498	1	0	0	0	1	11	71.19833266
440	1	3T	42	7	42	9000	15	40	11	0	N	T	12		2	N		0.171882	0	1	0	0	1	8	46.54355895
441	1	3T	42	7	56	9300	15	40	10	4	N	T	12		2	N		0.111668	0	0	0	0	0	6	53.73070172
442	1	3T	42	7	494	7700	15	35	13	0	Y	T	12		4	Y		0.106969	0	0	0	0	0	9	84.13652554
443	1	3T	46	4	55	11200	14	35	13	0	Y	T	13		2	Y		0.201671	0	1	0	0	1	12	59.50285366
444	2	3T	46	4	72	9900	14	35	13	0	Y	T	11		2	Y		0.284771	0	0	0	0	0	28	98.32461873
445	1	3T	46	4	72	9900	14	35	13	0	Y	T	11		3	Y		0.158779	0	1	0	0	1	6	37.78837252
446	1	3T	46	4	160	12300	13	45	13	0	N	T	16		2	Y		0.150978	0	0	0	0	0	0	0
447	1	3T	46	4	160	12300	13	45	13	0	Y	T	16		2	Y		0.153109	0	1	1	0	2	0	0
448	1	3T	46	4	160	18900	13	35	13	0	N	T	12		2	Y		0.119131	1	1	1	0	3	0	0
449	1	3T	46	7	728	23000	14	40	12	0	N	T	14		2	Y		0.164211	1	0	0	0	1	10	60.89726023
450	2	4D	7	2	17	9100	2	60	12	0	N	Grass	N/A		0			0.378216	0	0	0	0	0	3	7.931975379
451	3	4D	7	2	17	11000	2	60	12	6	N	Grass	N/A		0			0.903571	0	0	0	0	0	1	1.106719893
452	1	4D	7	2	278	49600	13	50	12	2	N	Grass	N/A		4	N		0.262463	0	1	1	0	2	0	0
453	1	4D	7	2	278	49600	13	55	12	0	N	Grass	N/A		4	N		0.259776	0	0	1	0	1	0	0
454	1	4D	7	4	170	21300	3	55	12	4	N	Grass	N/A		0			0.276185	0	0	0	0	0	0	0
455	1	4D	7	4	170	23300	3	55	12	2	N	Grass	N/A		0			0.122909	0	0	0	0	0	0	0
456	1	4D	26	2	17	15100	13	55	12	0	N	Grass	N/A		4	N		0.212049	0	0	0	0	0	1	4.715891138
457	1	4D	26	2	17	21000	13	55	12	0	N	Grass	N/A		4	N		0.137629	0	0	0	0	0	4	29.06364211
458	1	4D	26	2	17	28000	13	45	12	2	N	Grass	N/A		4	N		0.257492	1	1	1	0	3	5	19.41807901
459	5	4D	26	2	17	35800	12	55	12	2	N	Grass	N/A		4	N		1.774227	4	1	3	0	8	1	0.563625737
460	1	4D	26	2	17	41700	12	55	12	2	N	Grass	N/A		4	N		0.125571	0	0	0	0	0	0	0
461	1	4D	26	2	17	44700	12	55	12	0	N	Grass	N/A		4	N		0.472091	1	1	0	1	3	0	0
462	2	4D	26	2	501	17200	3	60	11	0	N	Grass	N/A		0			1.121917	1	0	0	1	2	6	5.347989201
463	1	4D	26	2	501	17200	3	60	12	0	N	Grass	N/A		0			0.168899	2	0	0	0	2	0	0
464	1	4D	26	2	501	21200	3	55	12	0	N	Grass	N/A		0			0.157001	0	0	0	0	0	1	6.369386182
465	1	4D	26	2	501	21200	3	60	12	0	N	Grass	N/A		0			0.411768	0	0	1	0	1	8	19.428416
466	2	4D	26	2	501	24100	3	60	11	0	N	Grass	N/A		0			0.827463	2	0	0	0	2	8	9.668106006
467	1	4D	26	2	501	24100	3	60	12	0	N	Grass	N/A		0			0.310236	0	0	0	0	0	1	3.223352545
468	6	4D	26	4	9	6100	2	60	11	0	N	Grass	N/A		0			2.747888	1	0	0	0	1	5	1.819579255

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
469	6	4D	26	4	9	6100	2	60	12	0	N	Grass	N/A		0			3.280746	3	0	0	0	3	8	2.438469787
470	2	4D	26	4	9	9200	2	60	12	2	N	Grass	N/A		0			0.895085	0	0	0	0	0	12	13.40654798
471	1	4D	26	4	9	9200	2	60	12	4	N	Grass	N/A		0			0.240845	2	0	0	0	2	1	4.152047998
472	1	4D	26	4	9	19800	2	60	12	2	N	Grass	N/A		0			0.377337	1	0	0	0	1	3	7.950452778
473	2	4D	26	4	22	5100	2	60	12	2	N	Grass	N/A		0			1.648487	1	0	0	0	1	0	0
474	2	4D	26	4	22	5600	2	60	12	2	N	Grass	N/A		0			1.359934	1	0	0	0	1	0	0
475	9	4D	26	4	22	7900	2	60	12	2	N	Grass	N/A		0			5.217903	5	0	1	1	7	0	0
476	4	4D	26	4	22	12100	2	60	12	2	N	Grass	N/A		0			2.08911	3	0	0	0	3	0	0
477	1	4D	26	4	22	16300	2	60	12	2	N	Grass	N/A		0			0.783794	2	0	0	0	2	0	0
478	1	4D	27	2	17	3200	15	45	12	0	N	Grass	N/A		4	N		0.123168	0	0	0	0	0	1	8.118991946
479	2	4D	27	2	17	9300	2	60	11	0	N	Grass	N/A		0			0.490297	0	1	0	0	1	6	12.23748055
480	1	4D	32	2	21	11600	13	45	12	2	N	Bituminous	N/A	5	4	Y		0.151268	0	0	1	0	1	2	13.22156702
481	2	4D	32	2	321	18600	2	55	11	0	N	Grass	N/A		0			0.472342	0	0	0	0	0	7	14.81977042
482	1	4D	32	2	321	18600	2	55	12	0	N	Grass	N/A		0			0.209111	0	0	0	0	0	6	28.69289516
483	2	4D	38	2	21	6200	3	55	13	2	N	Grass	N/A		0			0.247101	0	0	0	0	0	0	0
484	1	4D	38	2	301	6700	2	60	11	0	N	Grass	N/A		0			0.3223	0	0	0	0	0	5	15.51349674
485	3	4D	38	2	301	6900	3	60	12	0	N	Grass	N/A		0			0.763287	1	0	0	0	1	10	13.10123191
486	1	4D	38	2	301	7100	3	60	12	0	N	Grass	N/A		0			0.234218	1	0	0	0	1	2	8.539053361
487	1	4D	38	2	301	10800	3	60	11	0	N	Grass	N/A		0			0.205225	0	0	0	0	0	2	9.745401389
488	1	4D	38	2	301	12600	3	60	11	2	N	Grass	N/A		0			0.162174	0	0	0	0	0	3	18.4986496
489	1	4D	38	2	301	13700	2	60	11	0	N	Grass	N/A		0			0.371423	3	0	1	0	4	7	18.84643654
490	1	4D	39	2	76	16300	13	45	12	8	N	Grass	N/A		4	N		0.174545	1	0	0	0	1	1	5.729181586
491	1	4D	39	2	123	15900	2	65	12	2	N	Grass	N/A		0			0.645871	2	0	0	0	2	0	0
492	2	4D	39	2	123	16100	2	65	12	2	N	Grass	N/A		0			1.1236	2	0	0	0	2	0	0
493	2	4D	39	2	123	17300	2	65	12	2	N	Grass	N/A		0			0.512567	2	0	1	1	4	0	0
494	1	4D	39	2	123	36000	13	55	12	8	N	Grass	N/A		4	N		0.293934	0	0	1	0	1	9	30.61911858
495	1	4D	40	4	215	3200	3	55	12	2	N	Bituminous	N/A	3	4	N		0.247141	0	0	0	0	0	5	20.2313659
496	2	4D	40	4	215	5000	3	55	12	2	N	Bituminous	N/A	3	4	N		0.40489	3	0	0	0	3	1	2.469806614
497	1	4D	42	2	176	10900	2	55	12	2	N	Grass	N/A		0			0.414663	0	0	0	0	0	0	0
498	2	4D	42	2	221	7000	3	55	12	2	N	Grass	N/A		0			0.599308	0	0	0	0	0	2	3.337182217
499	1	4D	46	2	21	18700	2	55	12	0	N	Grass	N/A		4	N		0.296788	1	0	1	0	2	1	3.369408467
500	2	4D	46	2	321	10700	3	45	12	2	N	Bituminous	N/A	4	0			0.287311	0	0	1	0	1	10	34.80548952
501	2	4D	46	4	901	8500	3	50	-1	0	N	Grass	N/A		4	Y		0.12687	0	0	0	0	0	0	0
502	1	4D	46	4	901	13400	13	55	12	2	Y	Grass	N/A		4	N		0.138391	0	0	0	0	0	0	0
503	1	4U	7	7	44	13500	15	35	-1	2	N		N/A		4	N		0.17038	0	0	0	0	0	2	11.73846696
504	1	4U	27	2	17	5200	15	45	12	6	N		N/A		4	N		0.171961	0	1	0	0	1	10	58.15272068
505	1	4U	27	2	17	6800	15	35	12	8	N		N/A		4	Y		0.121676	0	0	0	1	1	12	98.62257142
506	1	4U	27	2	17	6800	15	45	-1	8	N		N/A		4	Y		0.213593	0	0	0	0	0	7	32.77260959
507	1	4U	27	2	17	9200	15	35	12	6	Y		N/A		4	Y		0.4026	0	0	0	2	2	21	52.1609538

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
508	1	4U	38	2	21	3600	3	30	-1	0	Y		N/A		4	Y		0.152922	0	0	0	0	0	8	52.31425171
509	1	4U	38	2	78	3500	2	30	13	0	N		N/A		4	Y		0.43241	0	0	0	0	0	26	60.12811915
510	1	4U	38	2	178	4450	3	35	-1	2	N		N/A		4	N		0.469713	0	0	0	0	0	19	40.45023238
511	1	4U	38	2	178	8700	13	45	-1	0	Y		N/A		4	Y		0.534762	0	0	0	0	0	22	41.13979677
512	1	4U	38	2	321	6900	2	35	12	0	N		N/A		4	Y		0.679035	0	1	0	0	1	20	29.45356278
513	1	4U	38	2	601	14800	13	45	-1	0	Y		N/A		4	N		0.277996	0	1	0	0	1	16	57.55478496
514	1	4U	38	4	6	3800	3	30	-1	0	Y		N/A		4	Y		0.286771	0	0	1	0	1	14	48.8194413
515	1	4U	38	4	6	4100	3	30	-1	0	Y		N/A		4	Y		0.215188	0	0	0	0	0	9	41.82389353
516	1	4U	38	7	94	13900	14	40	13	0	Y		N/A		4	N		0.187485	0	0	0	0	0	13	69.33888044
517	1	4U	39	2	178	10400	14	35	10	0	Y		N/A		4	Y		0.182504	0	0	0	0	0	15	82.1899794
518	1	4U	39	4	8	5666.666667	14	35	13	0	N		N/A		4	Y		0.533728	0	1	0	0	1	13	24.35697584
519	1	4U	39	4	8	9800	14	30	-1	0	Y		N/A		4	Y		0.090956	0	0	0	0	0	2	21.98865385
520	1	4U	39	4	8	9800	14	30	10	0	Y		N/A		4	Y		0.176865	0	0	0	0	0	7	39.57820937
521	1	4U	39	4	93	11200	14	25	10	0	Y		N/A		4	Y		0.185195	0	0	0	0	0	4	21.59885526
522	1	4U	39	4	93	14300	14	25	-1	0	Y		N/A		4	Y		0.175924	0	0	0	0	0	0	0
523	2	4U	39	4	93	16300	14	40	12	0	Y	Bituminous	N/A	2	4	Y		0.626099	0	7	1	0	8	38	60.69327694
524	1	4U	39	7	320	9300	14	35	-1	4	N		N/A		4	Y		0.480274	0	2	2	0	4	6	12.49286865
525	1	4U	39	7	320	9300	14	35	-1	4	N		N/A		4	Y		0.107218	0	0	0	0	0	0	0
526	1	4U	39	7	320	10620	14	35	-1	6	N		N/A		4	Y		0.243022	0	0	0	0	0	4	16.4594152
527	1	4U	40	2	1	17300	13	35	-1	0	Y		N/A		4	Y		0.099356	1	0	0	0	1	8	80.51853939
528	1	4U	40	2	321	8300	13	40	-1	0	Y		N/A		4	Y		0.303965	0	0	1	0	1	12	39.4782294
529	1	4U	40	2	321	8400	13	40	12	0	Y		N/A		4	Y		0.282216	2	1	1	0	4	14	49.60739292
530	1	4U	40	4	48	19800	13	45	11	0	Y		N/A		4	N		0.133696	0	0	0	0	0	6	44.87793202
531	2	4U	40	4	262	22100	14	40	-1	0	N		N/A		4	Y		0.662742	2	4	2	1	9	39	58.84642893
532	1	4U	40	4	262	22100	14	40	12	0	N		N/A		4	Y		0.162573	0	0	2	0	2	8	49.20866319
533	1	4U	42	4	11	4100	3	35	-1	0	N		N/A		4	N		0.133169	0	0	0	0	0	9	67.58329641
534	1	4U	42	4	146	4600	4	35	11	0	Y		N/A		4	Y		0.167786	0	0	0	0	0	8	47.67978258
535	1	4U	46	2	321	9600	14	35	11	0	Y		N/A		4	Y		0.195154	0	0	0	0	0	0	0
536	1	4U	46	4	5	11100	13	35	9	0	Y		N/A		4	Y		0.21685	0	0	0	0	0	11	50.72630851
537	1	5T	7	2	17	11000	2	50	-1	6	N	T	14		4	N		0.151754	0	0	0	0	0	4	26.35844854
538	1	5T	7	2	17	11000	2	50	-1	6	N	T	15		4	N		0.158373	0	0	0	0	0	1	6.314207599
539	1	5T	7	2	17	11000	2	60	12	6	N	T	14		4	N		0.14488	0	0	0	0	0	0	0
540	1	5T	7	2	21	12800	2	50	-1	0	N	T	14		4	Y		1.046727	0	1	0	0	1	16	15.28574308
541	1	5T	7	2	21	12800	2	50	13	0	N	T	13		4	Y		0.215576	0	0	0	0	0	2	9.27747059
542	1	5T	7	2	21	13400	13	50	-1	0	N	T	14		4	Y		0.323711	0	0	0	0	0	9	27.80257699
543	1	5T	7	2	21	23000	13	40	-1	0	N	T	0		4	Y		0.175542	0	2	4	1	7	12	68.35970879
544	1	5T	7	2	21	23000	13	40	11	0	N	T	12		4	Y		0.150087	0	0	2	0	2	4	26.65120897
545	1	5T	7	2	21	29400	13	45	-1	0	N	T	15		4	Y		0.14783	0	0	3	0	3	3	20.29358046
546	1	5T	7	2	21	29400	13	45	11	0	N	T	12		4	Y		0.154325	0	0	3	0	3	3	19.43949457

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
547	1	5T	7	2	21	37800	13	40	12	0	Y	T	15		4	Y		0.217343	0	4	4	1	9	12	55.21226817
548	1	5T	7	2	278	49600	13	45	12	0	N	T	15		4	Y		0.217812	0	1	0	0	1	7	32.13780692
549	1	5T	7	4	170	12500	14	55	-1	8	N	T	14		4	N		0.433063	0	0	0	0	0	0	0
550	2	5T	7	4	170	12500	14	55	-1	8	N	T	15		4	N		0.758976	0	0	1	0	1	6	7.905388313
551	1	5T	7	4	170	12500	14	55	12	8	N	T	16		4	N		0.3992	0	0	0	0	0	4	10.02004008
552	1	5T	7	4	170	17400	14	45	-1	0	Y	T	15		4	Y		0.103813	0	0	0	0	0	2	19.26540992
553	1	5T	7	4	170	21300	3	55	-1	4	N	T	14		4	N		0.257479	0	0	1	0	1	1	3.883811884
554	2	5T	7	4	170	21500	3	45	-1	4	N	T	15		4	N		0.498208	0	0	0	0	0	5	10.03596891
555	1	5T	7	4	170	23300	3	55	12	2	N	T	12		4	N		0.137564	0	0	0	0	0	0	0
556	1	5T	7	4	280	14300	13	35	-1	0	N	T	17		4	Y		0.260103	0	2	2	0	4	4	15.37852312
557	1	5T	7	4	280	17700	13	35	13	0	N	T	14		4	Y		0.206908	0	0	0	0	0	5	24.16532952
558	1	5T	7	4	280	17700	13	45	13	0	N	T	15		4	Y		0.20603	0	0	1	1	2	2	9.707324176
559	1	5T	7	4	280	18600	13	35	-1	0	N	T	15		4	Y		0.155699	0	0	0	0	0	3	19.26794649
560	2	5T	7	4	802	14300	14	45	-1	0	N	T	15		4	Y		0.486263	0	0	0	0	0	14	28.79100405
561	1	5T	26	2	17	27100	13	45	12	2	N	T	16		4	N		0.148358	0	2	0	0	2	7	47.18316505
562	1	5T	26	2	501	17200	3	45	12	0	N	T	15		4	N		0.279231	0	0	0	0	0	8	28.65011406
563	1	5T	26	2	501	17200	3	45	12	0	N	T	15		4	Y		0.426565	0	0	0	0	0	6	14.06585163
564	3	5T	26	2	501	29900	13	45	12	0	N	T	15		4	Y		0.705675	2	0	4	0	6	32	45.34665391
565	1	5T	26	2	501	40800	13	45	12	8	N	T	16		4	N		0.149029	0	0	0	0	0	7	46.97072382
566	2	5T	26	2	501	40800	13	50	12	8	N	T	16		4	N		0.504064	0	1	0	0	1	24	47.61300152
567	2	5T	26	2	701	12800	14	45	12	0	Y	T	14		4	Y		0.425692	0	0	3	0	3	16	37.5858602
568	1	5T	26	4	9	19800	2	45	12	0	N	T	14		4	N		0.174326	0	0	2	0	2	8	45.89103175
569	1	5T	26	4	9	25900	13	40	12	2	N	T	15		4	N		0.309169	0	0	0	0	0	6	19.40686162
570	1	5T	26	4	544	19200	14	45	-1	0	Y	T	13		4	Y		0.370988	1	0	0	1	2	9	24.25954478
571	1	5T	26	4	544	25000	14	45	11	4	N	T	13		4	N		0.292408	1	0	1	0	2	0	0
572	1	5T	26	4	544	25900	14	45	-1	0	N	T	12		4	Y		0.502363	1	0	1	0	2	25	49.7648115
573	2	5T	26	4	544	25900	14	45	-1	0	N	T	13		4	Y		0.53357	0	0	1	1	2	11	20.61585172
574	2	5T	26	4	544	25900	14	45	-1	0	N	T	14		4	Y		0.372314	0	1	1	0	2	7	18.80133436
575	1	5T	26	4	544	26600	14	45	-1	0	N	T	12		4	Y		0.793333	3	1	2	0	6	31	39.07564667
576	1	5T	26	4	544	26600	14	45	-1	0	N	T	13		4	Y		0.280351	1	0	0	0	1	9	32.10261422
577	1	5T	26	4	544	32000	14	45	12	0	N	T	15		4	Y		0.225054	0	0	1	0	1	10	44.43378034
578	2	5T	26	4	544	32800	14	45	12	0	N	T	15		4	Y		0.412929	3	0	1	0	4	9	21.79551448
579	1	5T	26	4	544	32800	14	45	12	0	N	T	16		4	Y		0.279449	3	2	0	0	5	8	28.62776392
580	1	5T	26	4	707	18600	14	40	12	0	N	T	16		4	Y		0.267524	1	1	1	0	3	9	33.64184148
581	2	5T	26	4	707	24600	14	40	12	0	N	T	15		4	Y		0.774528	2	1	5	0	8	55	71.01098992
582	1	5T	27	2	17	10200	3	35	13	0	N	T	13		4	Y		0.108792	0	0	0	0	0	9	82.72667108
583	1	5T	27	4	170	22200	3	55	12	4	N	T	15		4	N		0.22847	0	0	0	0	0	2	8.753884536
584	1	5T	32	2	1	12100	3	55	-1	0	N	T	15		4	Y		0.436312	2	0	0	0	2	23	52.71457122
585	5	5T	32	2	1	12100	3	55	12	2	N	T	15		4	N		3.761761	1	0	0	0	1	104	27.64662614

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
586	1	5T	32	2	1	19000	13	45	-1	0	N	T	15		4	Y		0.198708	2	0	0	0	2	12	60.39012018
587	1	5T	32	2	1	19000	13	45	12	0	N	T	14		4	Y		0.249132	0	0	2	0	2	10	40.13936387
588	3	5T	32	2	1	19000	13	45	12	0	N	T	15		4	Y		0.544517	0	0	0	0	0	20	36.72979907
589	1	5T	32	2	1	19000	13	55	-1	2	N	T	14		4	N		0.59556	1	0	1	0	2	17	28.5445631
590	2	5T	32	2	1	25400	13	45	12	0	N	T	14		4	Y		0.94154	1	1	1	0	3	26	27.61433396
591	2	5T	32	2	1	28500	13	45	12	0	N	T	14		4	Y		0.49382	1	1	1	0	3	15	30.37544044
592	2	5T	32	2	1	28500	13	45	12	0	N	T	15		4	Y		1.0511	2	1	3	0	6	22	20.93045381
593	1	5T	32	2	1	30400	13	45	12	0	N	T	13		4	Y		0.163716	0	1	2	0	3	4	24.43255393
594	2	5T	32	2	1	30400	13	45	12	0	N	T	14		4	Y		0.643144	1	4	5	0	10	25	38.87154354
595	2	5T	32	2	1	39100	13	45	12	0	N	T	14		4	Y		0.56849	1	0	2	1	4	21	36.93996376
596	1	5T	32	2	21	20300	13	45	-1	8	N	T	15		4	N		0.104189	0	0	0	0	0	2	19.1958844
597	3	5T	32	2	21	22200	13	35	-1	4	N	T	14		4	Y		0.478148	0	0	0	0	0	40	83.65610648
598	1	5T	32	2	21	22200	13	45	-1	0	N	T	15		4	Y		0.255829	2	1	0	0	3	16	62.54177595
599	3	5T	32	2	321	10400	2	45	12	0	N	T	15		4	Y		1.494442	0	0	1	0	1	36	24.08925873
600	1	5T	32	2	321	18600	2	40	12	0	N	T	16		4	Y		0.282554	0	0	1	0	1	9	31.85231849
601	7	5T	32	2	378	9900	2	55	12	2	N	T	15		4	N		2.145514	6	1	2	0	9	42	19.57572871
602	1	5T	32	2	378	11700	2	40	12	0	N	T	15		4	Y		0.356953	0	0	0	0	0	13	36.41936053
603	1	5T	32	2	378	11700	2	55	12	2	N	T	14		4	N		0.964584	0	0	0	0	0	22	22.80775961
604	3	5T	32	2	378	11700	2	55	12	2	N	T	15		4	N		1.710027	1	0	0	0	1	30	17.54358265
605	1	5T	32	2	378	11700	2	55	12	2	N	T	16		4	N		0.70967	2	0	0	0	2	21	29.59121845
606	3	5T	32	2	378	29600	13	45	-1	0	N	T	15		4	Y		1.789164	3	2	2	0	7	50	27.94601277
607	1	5T	32	2	378	29600	13	45	-1	0	N	T	16		4	Y		0.483162	1	1	0	0	2	11	22.76669109
608	1	5T	32	2	378	31600	13	45	-1	0	N	T	15		4	Y		0.230766	0	1	1	0	2	12	52.00072801
609	2	5T	32	2	378	33400	13	45	-1	0	N	T	15		4	Y		0.280731	0	1	0	2	3	10	35.62128871
610	2	5T	32	4	6	13600	14	45	-1	4	N	T	15		4	Y		0.547086	1	0	0	1	2	8	14.62292948
611	2	5T	32	4	6	13600	14	45	-1	4	N	T	16		4	Y		0.411998	0	0	0	0	0	9	21.84476624
612	1	5T	32	4	6	13600	14	45	11	4	N	T	15		4	Y		0.163171	0	0	1	0	1	0	0
613	1	5T	32	4	6	13600	14	45	12	4	N	T	15		4	Y		0.161257	0	0	0	0	0	0	0
614	2	5T	32	4	6	18100	14	45	12	4	N	T	13		4	Y		0.794676	3	2	1	1	7	15	18.87561723
615	3	5T	32	4	60	12800	14	45	-1	4	N	T	15		4	Y		1.509896	0	0	0	0	0	21	13.90824269
616	1	5T	32	4	60	25000	14	40	12	0	N	T	16		4	Y		0.244765	0	1	2	0	3	15	61.28327171
617	1	5T	32	4	302	10000	3	35	13	0	N	T	13		4	Y		0.386534	1	0	0	0	1	19	49.15479621
618	1	5T	32	4	302	10000	3	45	12	4	N	T	13		4	N		0.218722	0	0	1	0	1	11	50.29215168
619	3	5T	32	4	302	11600	13	45	11	4	N	T	12		4	N		0.789581	0	0	0	0	0	39	49.39328581
620	1	5T	32	4	302	13600	13	45	-1	0	N	T	13		4	Y		0.108005	0	0	0	0	0	2	18.51766122
621	1	5T	32	4	302	13600	13	45	-1	0	N	T	15		4	Y		0.247074	0	0	0	0	0	5	20.23685212
622	1	5T	32	4	302	14400	13	35	-1	0	N	T	15		4	Y		0.122226	1	0	0	0	1	4	32.72626119
623	2	5T	32	4	302	14400	13	45	12	0	N	T	17		4	Y		0.859681	2	0	0	0	2	16	18.61155475
624	1	5T	32	4	302	14400	13	55	12	0	N	T	17		4	Y		0.430129	0	0	0	0	0	1	2.32488393

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
625	1	5T	32	4	302	14400	13	55	12	0	N	T	18		4	Y		0.447593	2	1	0	0	3	5	11.17086282
626	1	5T	32	4	302	31700	13	45	-1	0	N	T	17		4	Y		0.192486	0	0	0	0	0	7	36.36628118
627	1	5T	32	4	302	31700	13	45	12	0	N	T	13		4	Y		0.132113	0	0	0	0	0	5	37.84638908
628	2	5T	32	7	36	14300	14	40	12	0	N	T	14		4	Y		0.294601	0	0	1	0	1	2	6.788843215
629	1	5T	32	7	36	14300	14	40	12	0	N	T	15		4	Y		0.175562	1	0	0	0	1	2	11.39198688
630	1	5T	32	7	36	17200	14	40	11	0	N	T	15		4	Y		0.13296	0	0	0	0	0	5	37.60529483
631	1	5T	32	7	36	19000	14	40	11	0	N	T	14		4	Y		0.10064	1	0	0	0	1	1	9.936406995
632	1	5T	32	7	36	20900	14	40	11	0	N	T	14		4	Y		0.0972	1	0	1	0	2	1	10.28806584
633	1	5T	32	7	36	23000	14	40	12	0	N	T	14		4	Y		0.280252	2	0	1	0	3	17	60.65969199
634	1	5T	38	2	21	17200	14	45	12	0	Y	T	16		4	Y		0.207891	0	0	1	0	1	3	14.43063913
635	1	5T	38	2	178	6200	15	45	12	0	N	T	15		4	Y		0.356666	0	0	1	0	1	15	42.05615338
636	1	5T	38	2	178	28400	13	45	12	0	N	T	15		4	Y		0.141251	0	0	0	0	0	4	28.31838359
637	1	5T	38	2	301	13700	2	45	-1	0	N	T	14		4	Y		0.150474	0	0	0	0	0	6	39.87399817
638	1	5T	38	2	301	13700	2	45	12	0	N	T	14		4	Y		0.184532	1	0	0	0	1	1	5.4191143
639	1	5T	38	2	321	4000	2	55	-1	4	N	T	13		4	N		0.830598	0	0	0	0	0	11	13.24347037
640	2	5T	38	2	321	4200	2	45	-1	0	N	T	12		4	Y		0.548305	1	0	0	0	1	7	12.76661712
641	1	5T	38	2	321	4200	2	45	-1	4	N	T	14		4	N		0.494019	1	0	0	0	1	2	4.048427287
642	1	5T	38	2	321	4200	2	45	12	4	N	T	13		4	N		0.377931	0	0	0	0	0	3	7.937956929
643	1	5T	38	2	321	6900	2	45	-1	0	N	T	12		4	Y		0.482626	0	0	0	0	0	2	4.143995558
644	1	5T	38	2	601	7000	2	55	12	0	N	T	15		4	Y		0.402153	0	0	0	0	0	7	17.40631053
645	1	5T	38	2	601	7600	2	55	-1	0	N	T	16		4	N		0.199118	0	0	0	0	0	0	0
646	1	5T	38	2	601	13300	13	55	-1	0	Y	T	18		4	N		0.229916	0	0	0	0	0	3	13.04824371
647	1	5T	38	2	601	25500	2	45	-1	0	Y	T	18		4	N		0.197866	0	0	0	0	0	9	45.48532845
648	1	5T	38	4	33	6500	15	55	11	0	N	T	15		4	N		0.282133	1	0	0	0	1	5	17.72213814
649	1	5T	38	4	33	6500	15	55	11	2	N	T	14		4	N		0.400327	0	0	0	0	0	2	4.995915839
650	1	5T	38	4	33	6500	15	55	12	2	N	T	14		4	N		0.306693	1	0	0	0	1	1	3.26058958
651	1	5T	38	7	49	7200	15	45	12	0	N	T	16		4	Y		0.17519	0	0	0	0	0	5	28.54044181
652	1	5T	38	7	49	8900	4	45	12	0	N	T	16		4	Y		0.371753	0	0	0	0	0	6	16.1397487
653	1	5T	38	7	94	13500	4	45	-1	0	N	T	16		4	Y		0.295246	0	0	1	0	1	3	10.16101827
654	1	5T	39	2	76	13200	13	40	11	0	N	T	15		4	Y		0.246797	0	0	1	0	1	6	24.31147866
655	1	5T	39	2	76	18600	13	55	-1	8	N	T	17		4	Y		0.22702	0	0	0	0	0	3	13.21469474
656	2	5T	39	2	76	23600	13	40	12	0	Y	T	14		4	Y		0.299686	0	1	3	0	4	27	90.0942987
657	1	5T	39	2	76	32900	13	40	12	0	Y	T	14		4	Y		0.173212	0	1	2	0	3	0	0
658	1	5T	39	2	123	34900	13	45	-1	0	Y	T	17		4	Y		0.33884	1	0	1	0	2	19	56.07366309
659	3	5T	39	2	123	36200	13	45	-1	0	Y	T	17		4	Y		0.620796	0	3	1	1	5	39	62.82256973
660	1	5T	39	4	8	12100	13	35	-1	0	Y	T	16		4	Y		0.159751	0	0	0	0	0	11	68.85715895
661	1	5T	39	4	8	12100	13	35	12	0	N	T	16		4	Y		0.274011	0	0	0	0	0	3	10.94846557
662	1	5T	39	4	93	17900	14	45	12	0	Y	T	15		4	Y		0.127236	0	0	0	0	0	12	94.3129303
663	1	5T	39	4	93	18000	14	40	-1	2	N	T	14		4	Y		0.147048	0	0	0	0	0	1	6.800500517

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
664	1	5T	39	4	93	18000	14	40	-1	2	Y	T	14		4	Y		0.107189	0	0	0	0	0	0	0
665	1	5T	39	4	93	20500	14	40	-1	4	Y	T	17		4	Y		0.138066	0	0	0	0	0	4	28.97165124
666	2	5T	39	4	93	21600	14	40	11	2	N	T	14		4	Y		0.230476	0	1	0	0	1	5	21.69423281
667	1	5T	39	4	93	21600	14	40	11	2	Y	T	14		4	Y		0.127115	0	0	0	0	0	0	0
668	1	5T	39	4	135	10700	13	35	12	0	N	T	15		4	Y		0.233477	0	3	3	0	6	6	25.6984628
669	1	5T	40	2	1	10800	3	45	-1	0	N	T	13		4	N		0.222056	1	0	0	0	1	0	0
670	1	5T	40	2	1	16300	13	45	-1	0	N	T	12		4	Y		0.303318	1	1	1	0	3	6	19.78121971
671	1	5T	40	2	1	16300	13	45	-1	0	N	T	14		4	N		0.1065	1	1	1	0	3	0	0
672	1	5T	40	2	1	17300	13	40	12	0	N	T	14		4	Y		0.198366	0	0	1	0	1	17	85.70017039
673	3	5T	40	2	1	21100	13	40	-1	0	N	T	14		4	Y		0.500724	0	1	2	0	3	23	45.93348831
674	1	5T	40	2	1	21100	13	40	-1	0	N	T	17		4	Y		0.173157	1	1	0	0	2	9	51.97595246
675	1	5T	40	2	1	25800	13	45	-1	0	N	T	14		4	N		0.205899	1	0	1	0	2	10	48.56750154
676	1	5T	40	2	1	31300	13	45	-1	0	N	T	14		4	N		0.282459	0	3	3	1	7	21	74.34707338
677	1	5T	40	2	1	31300	13	45	12	0	N	T	14		4	N		0.187763	0	0	0	0	0	3	15.97758877
678	2	5T	40	2	1	32500	13	40	12	0	N	T	14		4	Y		0.35023	0	0	2	1	3	22	62.81586386
679	1	5T	40	2	1	32500	13	45	-1	2	N	T	15		4	N		0.17189	0	0	1	0	1	3	17.45302228
680	1	5T	40	2	21	9000	14	40	-1	0	N	T	13		4	Y		0.157217	0	0	0	0	0	1	6.3606353
681	1	5T	40	2	21	9000	14	40	12	0	N	T	14		4	Y		0.299322	1	0	1	1	3	7	23.38618611
682	1	5T	40	2	76	20100	14	40	12	0	N	T	13		4	Y		0.243001	1	0	0	0	1	7	28.80646582
683	1	5T	40	2	76	20100	14	40	12	0	N	T	14		4	Y		0.212881	0	0	0	0	0	8	37.57968067
684	1	5T	40	2	176	16000	13	45	12	2	N	T	12		4	N		0.108931	0	0	0	0	0	0	0
685	1	5T	40	2	176	22000	13	40	12	0	N	T	15		4	Y		0.170601	1	2	1	0	4	9	52.75467318
686	1	5T	40	2	176	22000	13	45	11	2	N	T	12		4	N		0.260336	0	0	0	0	0	4	15.36475939
687	1	5T	40	2	176	22000	13	45	11	2	N	T	13		4	N		0.163595	0	0	0	0	0	4	24.45062502
688	1	5T	40	2	176	22000	13	45	12	0	N	T	14		4	Y		0.170296	0	1	0	0	1	8	46.97702823
689	2	5T	40	2	176	22000	13	45	12	0	N	T	15		4	Y		0.733984	2	1	2	0	5	24	32.69826045
690	1	5T	40	2	176	22000	13	45	12	2	N	T	12		4	N		0.256303	0	0	0	0	0	1	3.901632053
691	1	5T	40	2	176	36700	13	45	12	0	N	T	15		4	Y		0.126139	0	1	0	0	1	10	79.27762231
692	1	5T	40	2	321	6200	3	45	12	0	N	T	15		4	Y		0.197202	1	0	1	0	2	3	15.21282746
693	1	5T	40	2	321	6200	3	55	12	0	N	T	14		4	N		0.115861	0	0	0	0	0	4	34.52412805
694	1	5T	40	2	321	6200	3	55	12	2	N	T	14		4	N		0.601309	1	0	1	0	2	16	26.60861554
695	1	5T	40	2	321	13000	13	40	12	0	N	T	15		4	Y		0.346697	1	0	0	0	1	1	2.884363003
696	1	5T	40	2	321	13000	13	45	12	0	N	T	15		4	Y		0.737417	1	2	1	0	4	15	20.34127231
697	2	5T	40	4	12	14900	14	40	12	0	N	T	15		4	Y		0.397235	0	0	1	0	1	12	30.20881846
698	4	5T	40	4	215	8200	13	45	12	0	Y	T	12		4	Y		0.718993	1	1	0	0	2	10	13.90834125
699	1	5T	40	7	52	21900	14	45	-1	0	N	T	15		4	Y		0.142275	0	0	0	0	0	3	21.08592514
700	1	5T	40	7	52	21900	14	45	-1	0	N	T	16		4	Y		0.215899	0	0	1	0	1	2	9.263590846
701	1	5T	40	7	52	25000	14	40	-1	0	N	T	15		4	Y		0.162441	2	3	0	0	5	0	0
702	1	5T	40	7	52	25000	14	45	-1	0	N	T	15		4	Y		0.984761	2	3	0	0	5	9	9.139273387

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
703	2	5T	40	7	52	27400	3	45	-1	0	N	T	15		4	Y		0.323316	0	0	0	0	0	0	0
704	1	5T	42	2	29	8400	13	45	12	0	N	T	13		4	Y		0.115863	1	0	0	0	1	0	0
705	2	5T	42	2	29	8400	13	45	12	0	N	T	14		4	Y		0.619927	0	1	0	1	2	20	32.26186309
706	1	5T	42	2	29	8400	13	45	12	0	Y	T	15		4	Y		0.217992	0	0	0	0	0	11	50.46056736
707	1	5T	42	2	29	8600	13	45	-1	0	N	T	13		4	Y		0.108942	0	0	0	0	0	6	55.07517762
708	1	5T	42	2	29	8600	13	45	-1	0	N	T	14		4	Y		0.159816	0	0	0	0	0	5	31.28597888
709	2	5T	42	2	29	16100	13	45	12	6	N	T	12		4	N		0.495242	0	0	0	0	0	19	38.36508212
710	1	5T	42	2	29	20000	13	35	12	0	Y	T	16		4	Y		0.118563	0	0	0	0	0	3	25.30300347
711	1	5T	42	2	29	20000	13	45	12	0	Y	T	14		4	Y		0.109444	0	0	0	0	0	5	45.68546471
712	1	5T	42	2	176	11200	13	45	-1	0	N	T	13		4	N		0.242447	0	1	0	0	1	3	12.37383841
713	1	5T	42	2	176	11200	13	45	12	0	N	T	13		4	Y		0.308022	1	0	0	0	1	10	32.46521352
714	2	5T	42	2	176	11200	13	45	12	0	N	T	14		4	Y		0.462211	1	0	0	0	1	21	45.43379539
715	1	5T	42	2	176	13800	2	55	12	2	N	T	16		4	N		0.498767	2	0	0	0	2	5	10.02472096
716	1	5T	42	2	176	13800	2	55	12	2	N	T	18		4	N		0.601951	0	0	0	0	0	9	14.95138309
717	1	5T	42	2	176	15500	13	40	12	0	Y	T	13		4	Y		0.149248	0	2	0	0	2	8	53.60205832
718	1	5T	42	2	176	15500	13	45	-1	0	N	T	13		4	Y		0.153619	1	0	0	0	1	4	26.03844577
719	2	5T	42	2	176	15500	13	45	12	0	N	T	13		4	Y		0.494212	1	0	1	0	2	13	26.3045009
720	1	5T	42	2	176	15500	13	45	12	0	N	T	14		4	Y		0.180298	0	0	0	0	0	2	11.09274645
721	1	5T	42	2	176	18800	13	35	-1	0	Y	T	12		4	Y		0.1424	1	1	1	0	3	4	28.08988764
722	1	5T	42	2	176	18800	13	40	-1	0	Y	T	13		4	Y		0.221962	0	0	0	0	0	9	40.5474811
723	1	5T	42	2	176	18800	13	45	-1	0	N	T	12		4	Y		0.424454	0	0	0	0	0	19	44.76339014
724	1	5T	42	2	221	8900	3	35	-1	0	Y	T	14		4	Y		0.134298	0	0	0	0	0	6	44.67676362
725	1	5T	42	2	221	8900	3	45	-1	0	N	T	14		4	N		0.716839	2	0	1	0	3	11	15.34514724
726	1	5T	42	2	221	8900	3	45	12	0	N	T	13		4	Y		0.261963	0	0	1	0	1	8	30.53866386
727	1	5T	42	2	221	8900	3	45	12	0	N	T	14		4	Y		0.393045	0	0	0	1	1	16	40.70780699
728	1	5T	42	2	221	11500	13	55	12	2	N	T	16		4	N		0.16888	0	0	0	0	0	0	0
729	1	5T	42	2	221	18100	3	45	12	0	N	T	13		4	Y		0.219099	0	0	1	0	1	3	13.6924404
730	1	5T	42	4	9	20100	14	45	12	0	N	T	14		4	Y		0.104278	0	0	0	0	0	7	67.12825332
731	1	5T	42	4	9	21700	14	45	12	0	N	T	14		4	Y		0.180014	1	0	0	0	1	12	66.66148188
732	1	5T	42	4	56	9600	14	40	12	0	Y	T	14		4	Y		0.152399	0	0	1	0	1	8	52.49378277
733	2	5T	42	4	101	4300	3	55	12	4	N	T	15		4	N		0.806866	0	0	0	1	1	7	8.675542159
734	1	5T	42	4	101	4300	3	55	12	4	N	T	16		4	N		0.743518	0	0	0	0	0	6	8.069744108
735	1	5T	42	4	101	7700	14	45	-1	0	N	T	10		4	Y		0.151777	0	0	0	0	0	3	19.76584067
736	1	5T	42	4	101	7700	14	45	11	0	N	T	10		4	Y		0.212484	0	0	0	0	0	0	0
737	1	5T	42	4	101	10350	14	45	11	0	N	T	10		4	Y		0.408579	0	0	0	0	0	0	0
738	2	5T	42	4	101	15800	3	45	-1	0	N	T	13		4	Y		0.761464	0	0	2	0	2	23	30.20497358
739	1	5T	42	4	101	15800	3	45	-1	0	N	T	14		4	Y		0.280323	0	0	1	0	1	5	17.8365671
740	1	5T	42	4	101	15800	3	45	-1	0	N	T	15		4	Y		0.230255	0	0	0	0	0	8	34.74408808
741	1	5T	42	4	290	9400	15	45	-1	0	N	T	12		4	Y		0.308851	0	0	1	0	1	8	25.90245782

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
742	1	5T	42	4	290	9400	15	45	-1	0	N	T	13		4	Y		0.169283	0	0	0	0	0	10	59.07267711
743	1	5T	42	4	290	9400	15	45	-1	0	N	T	14		4	Y		0.130113	0	0	0	0	0	3	23.05688133
744	1	5T	42	4	290	9400	15	45	12	0	N	T	15		4	Y		0.29743	1	0	0	0	1	4	13.44854251
745	2	5T	42	4	290	9400	15	45	12	0	N	T	16		4	Y		0.662054	1	0	0	0	1	12	18.12540971
746	1	5T	42	4	290	9400	15	55	-1	4	N	T	14		4	N		0.545492	1	0	1	0	2	0	0
747	1	5T	42	4	296	22200	14	45	-1	0	N	T	12		4	Y		0.313515	1	0	2	0	3	11	35.08604054
748	1	5T	42	4	296	22200	14	45	-1	4	N	T	14		4	Y		0.190782	0	0	0	0	0	10	52.41584636
749	1	5T	42	4	296	22200	14	45	-1	4	N	T	15		4	Y		0.154799	0	0	0	0	0	8	51.67992041
750	1	5T	42	4	296	22200	14	45	12	4	N	T	14		4	N		0.109829	1	0	0	0	1	1	9.105063326
751	1	5T	42	4	296	22200	14	50	12	4	N	T	15		4	N		0.17663	2	0	2	0	4	1	5.661552398
752	1	5T	42	4	296	22200	14	50	12	4	N	T	15		4	Y		0.19979	0	0	0	0	0	8	40.04204415
753	1	5T	42	7	44	18100	15	35	11	0	N	T	13		4	Y		0.316234	0	1	0	0	1	10	31.62215322
754	1	5T	46	2	21	15800	13	45	10	0	N	T	13		4	Y		0.245614	0	0	1	0	1	4	16.28571661
755	1	5T	46	2	21	18200	13	45	10	0	N	T	11		4	Y		0.14625	0	0	0	0	0	6	41.02564103
756	1	5T	46	2	21	18200	13	45	11	0	N	T	16		4	Y		0.231112	0	0	0	0	0	12	51.92287722
757	1	5T	46	4	5	8800	13	45	12	2	N	T	15		4	N		0.101579	0	0	0	0	0	0	0
758	1	5T	46	4	5	13100	13	45	12	0	Y	T	12		4	Y		0.154501	0	0	0	0	0	6	38.8347001
759	1	5T	46	4	5	13100	13	45	13	0	Y	T	12		4	Y		0.152014	1	0	0	0	1	3	19.73502441
760	2	5T	46	4	5	15800	13	45	12	0	N	T	12		4	Y		0.307569	0	0	0	0	0	5	16.2565148
761	1	5T	46	4	5	15800	13	45	12	0	Y	T	13		4	Y		0.453046	0	0	1	0	1	3	6.621844139
762	2	5T	46	4	5	17600	14	35	12	0	Y	T	11		4	Y		0.28211	0	0	1	0	1	18	63.8048988
763	1	5T	46	4	5	17600	14	45	12	0	N	T	11		4	Y		0.215771	0	0	0	0	0	1	4.634543104
764	2	5T	46	4	49	18700	3	45	11	0	N	T	13		4	Y		0.500312	0	0	0	0	0	4	7.995011113
765	1	5T	46	4	49	18700	3	45	12	0	N	T	13		4	Y		0.481312	0	0	0	0	0	12	24.93185294
766	3	5T	46	4	49	25700	14	45	12	0	N	T	15		4	Y		1.111602	1	0	2	1	4	24	21.59046133
767	3	5T	46	4	160	29400	13	45	12	0	N	T	15		4	Y		0.83923	0	0	2	0	2	0	0
768	2	5T	46	4	160	29400	13	45	12	0	N	T	16		4	Y		0.62112	1	1	4	1	7	0	0
769	1	5T	46	4	161	12000	13	45	12	0	N	T	12		4	Y		0.147104	0	0	0	0	0	4	27.191647
770	1	5T	46	4	161	12000	13	50	-1	0	N	T	11		4	Y		0.202831	0	0	0	0	0	8	39.4417027
771	1	5T	46	4	161	12000	13	50	-1	0	N	T	12		4	Y		0.437082	0	0	1	0	1	9	20.5911019
772	5	5T	46	4	161	12000	13	55	-1	0	N	T	11		4	Y		1.865391	0	2	0	0	2	26	13.93809662
773	4	5T	46	4	161	12000	13	55	12	0	N	T	15		4	Y		1.639825	1	0	1	0	2	17	10.36695989
774	2	5T	46	4	161	19300	13	45	12	0	Y	T	15		4	Y		0.276556	0	2	0	0	2	2	7.231808386
775	2	5T	46	4	161	19300	13	45	12	0	Y	T	16		4	Y		0.269432	0	0	0	0	0	5	18.55755812
776	1	5T	46	4	161	23700	13	45	12	0	N	T	11		4	Y		0.249937	0	0	0	1	1	4	16.00403302
777	1	5T	46	4	161	23700	13	45	12	0	N	T	12		4	Y		0.181533	0	0	0	0	0	3	16.52592091
778	2	5T	46	4	161	23700	13	45	12	0	Y	T	13		4	Y		0.70281	0	0	2	0	2	11	15.6514563
779	1	5T	46	4	161	23700	13	45	12	0	Y	T	16		4	Y		0.131965	1	0	0	0	1	0	0
780	1	5T	46	4	274	9200	3	45	-1	0	N	T	15		4	Y		0.160201	0	0	0	0	0	5	31.21079144

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
781	2	5T	46	4	274	9200	3	50	12	0	N	T	15		4	Y		0.89325	1	0	0	0	1	14	15.67310383
782	3	5T	46	4	274	9200	3	55	-1	0	N	T	11		4	Y		0.982628	3	0	0	1	4	7	7.123753852
783	1	5T	46	4	274	9200	3	55	12	0	N	T	15		4	Y		0.60559	0	0	0	0	0	16	26.42051553
784	5	5T	46	4	274	9600	3	55	-1	0	N	T	11		4	Y		1.009099	0	0	0	0	0	20	19.81966091
785	2	5T	46	4	274	9600	3	55	-1	0	N	T	12		4	Y		0.604863	1	0	0	0	1	22	36.37187264
786	1	5T	46	4	901	8500	3	45	-1	0	N	T	15		4	Y		0.312675	0	0	0	0	0	13	41.57671704
787	1	5T	46	4	901	8500	3	50	-1	0	N	T	16		4	Y		0.2048	0	0	0	0	0	5	24.4140625
788	1	5T	46	4	901	13500	13	45	-1	0	N	T	14		4	N		0.166953	0	1	0	0	1	5	29.94854839
789	1	5T	46	4	901	13500	13	45	12	2	N	T	14		4	N		0.144774	0	0	0	0	0	0	0
790	1	5T	46	7	86	19900	14	40	12	0	Y	T	14		4	Y		0.350815	1	0	0	0	1	4	11.40202101
791	1	5T	46	7	98	18600	14	35	-1	0	N	T	15		4	Y		0.674162	0	0	0	0	0	14	20.76652199
792	1	5T	46	7	98	18600	14	45	12	0	Y	T	15		4	Y		0.259248	0	0	0	0	0	7	27.00117262
793	3	5T	46	7	98	20300	14	45	12	0	N	T	15		4	Y		1.453775	0	1	2	0	3	37	25.45098107
794		2U	7	4	46	11100	14	45	12	2	N		N/A		0	N		0.2649	3				4	1	3.7752
795		2U	7	4	46	8800	14	55	11	4	N		N/A		0	N		0.1843	3				4	0	0
796		2U	7	7	21	2900	4	55	10	0	N		N/A		0	Y	Level	0.251	0				1	0	0
797		2U	27	2	17	13100	2	55	11	2	N		N/A		0	Y	Level	0.821	2				15	0	0
798		2U	27	2	278	1600	3	55	12	0	N		N/A		0	Y	Level	0.1464	4				4	0	0
799		2U	27	2	321	2800	3	55	12	2	N		N/A		0	Y	Level	0.2056	0				0	0	0
800		2U	27	4	315	8000	4	55	12	0	N		N/A		0	Y	Level	0.1906	2				3	0	10.256
801		2U	27	4	462	2600	4	55	11	2	N		N/A		0	Y	Level	0.2753	0				1	0	0
802		2U	27	4	462	1600	4	55	11	0	N		N/A		0	Y	Level	0.157	2				4	0	4.1
803		2U	27	4	462	7700	3	55	11	0	N		N/A		0	Y	Level	0.2796	1				1	0	0
804		2U	27	7	54	2800	4	45	10	0	N		N/A		0	Y	Level	0.1843	8				10	0	0
805		2U	27	7	54	2800	4	45	10	0	N		N/A		0	Y	Level	0.9208	11				13	0	0
806		2U	27	7	442	5684	4	55	10	0	N		N/A		0	Y	Level	0.39	3				5	0	0
807		2U	26	2	378	6900	2	55	11	0	N		N/A		0	Y	Level	0.0859	2				3	0	11.9
808		2U	26	2	701	10500	3	50	11	0	N		N/A		0	Y	Level	0.2474	1				2	0	20.7
809		2U	26	2	701	7400	3	55	11	0	N		N/A		0	Y	Level	0.4149	7				10	0	7.57
810		2U	26	4	9	4200	2	45	11	2	N		N/A		0	Y	Level	0.1872	0				2	0	24
811		2U	26	4	9	4200	2	45	12	2	N		N/A		0	Y	Level	0.118	0				0	0	20.16
812		2U	26	4	9	6800	4	55	12	0	N		N/A		0	Y	Level	0.1309	0				0	0	13.9
813		2U	26	4	90	6100	3	45	12	0	N		N/A		0	Y	Level	0.1492	0				1	0	0
814		2U	26	4	90	6100	3	55	12	2	N		N/A		0	Y	Level	0.2663	3				4	0	8.97
815		2U	26	4	707	18600	14	45	12	0	N		N/A		0	N		0.225	6				10	0	13.3
816		2U	32	2	1	5900	3	55	12	0	N		N/A		0	Y	Level	0.0771	0				1	0	15.44
817		2U	32	2	178	3000	3	55	11	0	N		N/A		0	Y	Level	0.1025	0				0	0	4.65
818		2U	32	7	29	1200	4	45	9	0	N		N/A		0	Y	Moderate	0.196	1				1	0	21.1
819		2U	32	7	29	3800	4	45	10	0	N		N/A		0	Y	Moderate	0.1633	1				1	0	12.5

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
820		2U	32	7	29	3800	4	45	10	0	N		N/A		0	Y	Moderate	0.1384	1				1	0	0
821		2U	32	7	29	3800	4	45	10	0	N		N/A		0	Y	Moderate	0.0689	1				1	0	0
822		2U	32	7	29	3800	4	45	10	0	N		N/A		0	Y	Moderate	0.0788	1				1	0	0
823		2U	32	7	51	9500	4	50	10	0	N		N/A		0	Y	Level	0.21	2				2	0	6.9
824		2U	32	7	51	7200	4	50	10	0	N		N/A		0	Y	Level	0.1324	2				2	0	0
825		2U	32	7	73	2700	4	45	11	2	N		N/A		0	Y	Level	0.3458	3				5	0	21.2
826		2U	32	7	231	3100	4	45	10	2	N		N/A		0	Y	Moderate	0.2404	0				0	0	4.65
827		2U	32	7	233	5280	9	35	10	2	N		N/A		0	Y	Level	0.051	0				0	5	98.072
828		2U	32	7	233	4100	4	45	10	0	N		N/A		0	Y	Level	0.1658	1				2	0	6
829		2U	32	7	875	2600	15	40	11	0	N		N/A		0	N		0.1576	2				2	0	72.4
830		2U	32	7	875	2600	15	40	11	0	N		N/A		0	N		0.268	0				0	0	72.4
831		2U	38	2	21	4200	3	45	12	2	N		N/A		0	Y	Level	0.2213	1				1	0	23.1
832		2U	38	2	21	2800	3	55	12	2	N		N/A		0	Y	Level	0.104	0				0	0	0
833		2U	38	2	21	1450	3	55	11	2	N		N/A		0	Y	Level	0.1187	0				0	0	0
834		2U	38	2	176	2900	4	55	11	0	N		N/A		0	Y	Level	0.2776	2				2	0	3.14
835		2U	38	2	176	3500	4	35	11	0	N		N/A		0	Y	Level	0.1352	0				0	1	7.3963
836		2U	38	2	178	4200	3	45	11	0	N		N/A		0	Y	Level	0.3891	1				1	0	0
837		2U	38	2	178	3700	3	45	11	0	N		N/A		0	Y	Level	0.1932	1				2	0	14.8
838		2U	38	2	178	3700	3	45	11	0	N		N/A		0	Y	Level	0.1694	1				1	0	16.2
839		2U	38	2	321	4200	2	55	11	0	N		N/A		0	Y	Level	0.2488	2				2	0	2.7
840		2U	38	4	4	4800	3	55	12	0	N		N/A		0	Y	Level	0.2606	0				0	0	15.14
841		2U	38	4	6	4900	3	55	12	2	N		N/A		0	Y	Level	0.3313	3				5	0	0
842		2U	38	4	6	3700	3	55	12	2	N		N/A		0	Y	Level	0.2565	0				3	0	0
843		2U	38	4	6	3500	3	45	12	2	N		N/A		0	Y	Level	0.4255	0				0	0	4.7
844		2U	38	4	6	4000	3	55	12	2	N		N/A		0	Y	Level	0.142	0				0	0	0
845		2U	38	4	70	3100	3	55	12	0	N		N/A		0	Y	Level	0.1637	3				4	0	0
846		2U	38	4	70	3100	3	55	11	0	N		N/A		0	Y	Level	0.1069	0				0	2	18.7173
847		2U	38	4	70	3100	3	55	11	0	N		N/A		0	Y	Level	0.4471	3				4	0	24.9
848		2U	38	4	70	3100	3	55	11	0	N		N/A		0	Y	Level	0.3471	1				1	0	0
849		2U	38	4	400	1600	4	55	11	0	N		N/A		0	Y	Level	0.3158	0				1	0	12.84
850		2U	38	4	400	1750	4	55	11	0	N		N/A		0	Y	Level	0.1767	1				1	0	2.97
851		2U	38	4	400	1600	4	55	11	0	N		N/A		0	Y	Level	0.128	1				1	0	12.84
852		2U	38	4	400	1600	4	55	11	0	N		N/A		0	Y	Level	0.1128	1				2	0	11.88
853		2U	38	4	453	3000	4	35	11	0	N		N/A		0	Y	Level	0.1551	0				1	3	19.339
854		2U	38	7	39	850	4	55	10	2	N		N/A		0	Y	Level	0.343	0				0	0	0
855		2U	38	7	49	8900	4	45	11	2	N		N/A		0	Y	Level	0.4562	4				6	1	2.1918
856		2U	39	2	178	2600	3	50	10	0	N		N/A		0	Y	Level	0.117	3				3	3	10.5622
857		2U	39	2	178	7100	3	45	11	0	N		N/A		0	Y	Moderate	0.2768	3				4	4	32.2357
858		2U	39	2	178	6900	14	55	12	2	N		N/A		0	N		0.1876	2				4	2	19.0596

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
859		2U	39	4	93	4900	14	55	12	0	N		N/A		0	N		0.3717	3				3	2	16.1385
860		2U	39	4	133	3500	4	50	11	0	N		N/A		0	Y	Level	0.2245	0				0	1	5.9661
861		2U	39	4	133	3500	4	50	11	0	N		N/A		0	Y	Level	0.2061	1				3	1	5.9661
862		2U	39	4	135	6600	14	55	11	0	N		N/A		0	Y	Level	0.1182	0				1	2	15.217
863		2U	39	4	135	2100	4	55	11	0	N		N/A		0	Y	Moderate	0.1394	1				2	2	13.332
864		2U	39	4	135	2100	4	55	11	0	N		N/A		0	Y	Level	0.1271	0				0	0	0
865		2U	39	4	135	5200	4	55	11	0	N		N/A		0	Y	Level	0.0942	0				0	2	15.217
866		2U	39	4	135	3100	4	55	11	0	N		N/A		0	Y	Level	0.2049	0				0	0	0
867		2U	39	4	183	4800	3	45	12	0	N		N/A		0	Y	Level	0.2381	2				2	4	26.1103
868		2U	39	4	183	4600	14	55	11	2	N		N/A		0	Y	Level	0.1422	0				0	5	25.4979
869		2U	39	4	183	6400	3	55	11	2	N		N/A		0	Y	Level	0.5214	2				2	5	25.4979
870		2U	39	4	183	5900	3	55	11	0	N		N/A		0	Y	Level	0.1957	1				2	4	32.3078
871		2U	39	4	183	4800	3	45	12	0	N		N/A		0	Y	Level	0.1363	0				0	3	8.2779
872		2U	39	4	183	4600	14	55	11	2	N		N/A		0	Y	Level	0.138	1				1	5	25.4979
873		2U	39	4	183	10900	3	55	11	2	N		N/A		0	Y	Moderate	0.2114	3				4	0	0
874		2U	39	4	183	5900	3	55	11	0	N		N/A		0	Y	Moderate	0.1668	1				1	3	9.8018
875		2U	39	4	183	5900	3	55	11	0	N		N/A		0	Y	Moderate	0.2728	3				3	3	9.8018
876		2U	39	7	30	3500	15	35	10	0	N		N/A		0	N		0.1695	0				1	2	21.7052
877		2U	39	7	30	4800	15	35	10	0	N		N/A		0	N		0.0793	0				0	4	13.8486
878		2U	39	7	36	3900	4	45	10	0	N		N/A		0	Y	Moderate	0.1598	1				1	0	0
879		2U	39	7	160	1350	4	45	10	0	N		N/A		0	Y	Moderate	0.3461	2				2	0	0
880		2U	39	7	160	1350	4	45	10	0	N		N/A		0	Y	Moderate	0.2541	0				0	0	0
881		2U	39	7	160	2300	4	45	10	0	N		N/A		0	Y	Level	0.1754	0				1	0	0
882		2U	39	7	160	2300	4	45	10	0	N		N/A		0	Y	Level	0.2975	0				0	0	0
883		2U	39	7	221	4700	14	35	10	0	N		N/A		0	N		0.1944	0				0	1	7.254
884		2U	39	7	320	7700	14	45	12	2	N		N/A		0	N		0.204	0				1	0	0
885		2U	39	2	178	5700	3	50	11	0	N		N/A		0	Y	Level	0.1863	0				0	2	10.735
886		2U	39	4	8	9700	13	45	11	2	N		N/A		0	N		0.119	1				2	7	58.808
887		2U	39	4	93	7900	14	55	11	0	N		N/A		0	N		0.2911	2				4	4	13.742
888		2U	40	2	1	10800	3	45	12	0	N		N/A		0	Y	Level	0.206	9				15	0	0
889		2U	40	2	176	6800	4	55	11	0	N		N/A		0	Y	Level	0.406	2				2	0	25.2
890		2U	40	2	601	4200	2	55	13	0	N		N/A		0	Y	Moderate	0.1081	1				1	0	11.43
891		2U	40	4	215	3200	3	55	12	0	N		N/A		0	Y	Level	0.2198	0				0	0	0
892		2U	40	4	215	3200	3	55	12	0	N		N/A		0	Y	Level	0.1397	1				1	0	11.2
893		2U	40	4	215	3200	3	55	12	0	N		N/A		0	Y	Level	0.564	0				0	0	0
894		2U	40	7	52	11600	3	45	10	0	N		N/A		0	Y	Level	0.325	1				3	0	24.24
895		2U	40	7	52	19100	14	45	12	2	N		N/A		0	N		0.1424	2				5	0	5.33
896		2U	40	7	54	4500	4	40	11	0	N		N/A		0	Y	Level	0.2469	1				1	0	9.13
897		2U	40	7	54	4500	4	40	11	0	N		N/A		0	Y	Level	0.088	0				0	0	6.1

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
898		2U	40	7	54	4500	4	40	11	0	N		N/A		0	Y	Level	0.086	0				0	0	5.5
899		2U	40	7	54	4500	4	40	11	0	N		N/A		0	Y	Level	0.3674	0				0	0	9.13
900		2U	40	7	54	4500	4	40	11	0	N		N/A		0	Y	Level	0.3795	0				0	0	5.5
901		2U	40	7	83	4200	4	45	10	2	N		N/A		0	Y	Level	0.3763	1				2	0	16.74
902		2U	40	7	268	3500	15	55	11	2	N		N/A		0	N		0.1307	0				0	0	0
903		2U	40	7	268	5900	15	55	11	2	N		N/A		0	N		0.1977	2				2	0	2.2
904		2U	40	7	268	3500	15	55	11	2	N		N/A		0	N		0.5315	0				0	0	14.93
905		2U	40	7	268	3500	15	55	11	2	N		N/A		0	N		0.3862	4				4	0	9.27
906		2U	40	7	2200	2700	4	55	10	2	N		N/A		0	Y	Level	0.4196	0				1	0	18.9
907		2U	42	2	221	3000	4	45	11	0	N		N/A		0	Y	Level	0.1951	0				1	2	10.2507
908		2U	42	4	11	2700	3	55	12	0	N		N/A		0	Y	Moderate	0.2589	0				0	0	11.13
909		2U	42	4	11	3300	3	55	12	0	N		N/A		0	Y	Level	0.1828	0				0	0	17.86
910		2U	42	4	11	2700	3	55	12	0	N		N/A		0	Y	Level	0.3911	0				1	0	0
911		2U	42	4	11	4100	3	55	11	0	N		N/A		0	Y	Level	0.1633	1				2	0	8.5
912		2U	42	4	11	4100	3	40	11	0	N		N/A		0	Y	Level	0.1296	0				0	1	7.7147
913		2U	42	4	11	3300	3	55	12	0	N		N/A		0	Y	Level	0.1141	2				3	2	17.5348
914		2U	42	4	11	3300	3	55	12	0	N		N/A		0	Y	Level	0.3996	1				2	0	17.86
915		2U	42	4	11	3300	3	55	11	0	N		N/A		0	Y	Level	0.1885	1				1	0	17.3
916		2U	42	4	14	5200	14	55	12	2	N		N/A		0	N		0.1627	2				3	8	49.17
917		2U	42	4	56	3700	3	45	11	0	N		N/A		0	Y	Level	0.1988	1				2	0	14.8
918		2U	42	4	101	2700	4	45	11	0	N		N/A		0	Y	Level	0.1374	0				0	0	0
919		2U	42	4	101	2700	4	45	10	0	N		N/A		0	Y	Level	0.1994	2				6	5	25.0802
920		2U	42	4	101	2700	4	45	10	0	N		N/A		0	Y	Level	0.3074	1				2	0	16.64
921		2U	42	4	146	4600	4	55	12	0	N		N/A		0	Y	Level	0.3257	0				2	0	4.5
922		2U	42	4	146	2600	4	55	11	0	N		N/A		0	Y	Level	0.3861	1				1	0	4.7
923		2U	42	4	292	8300	4	45	12	2	N		N/A		0	Y	Level	0.5526	3				6	13	23.5252
924		2U	42	7	40	2400	14	40	10	0	N		N/A		0	N		0.1865	0				1	0	25.4
925		2U	42	7	42	3000	4	45	11	2	N		N/A		0	Y	Level	0.2961	2				2	8	27.0157
926		2U	42	7	42	3000	4	45	12	2	N		N/A		0	Y	Level	0.2971	0				0	2	6.7306
927		2U	42	7	43	850	4	35	10	0	N		N/A		0	Y	Level	0.3172	2				2	2	6.3056
928		2U	42	7	43	850	4	35	10	0	N		N/A		0	Y	Level	0.2227	1				1	1	4.4909
929		2U	42	7	43	850	4	35	10	0	N		N/A		0	Y	Level	0.1158	1				1	2	17.2727
930		2U	42	7	88	2700	15	45	11	2	N		N/A		0	N		0.2554	2				2	1	3.9159
931		2U	42	7	128	4510	9	35	9	0	N		N/A		0	Y	Level	0.1012	0				0	2	19.7587
932		2U	46	2	321	3400	3	55	12	2	N		N/A		0	Y	Level	0.2124	0				0	0	15.27
933		2U	46	4	5	9800	2	55	11	0	N		N/A		0	Y	Level	0.1823	1				2	4	21.9422
934		2U	46	4	5	9800	2	55	11	0	N		N/A		0	Y	Level	0.1386	0				1	4	28.8626
935		2U	46	4	5	9800	2	55	11	0	N		N/A		0	Y	Moderate	0.2002	1				2	0	22.33
936		2U	46	4	55	3900	3	55	12	0	N		N/A		0	Y	Level	0.1353	3				4	0	2.08

Aggregate Segment ID	Count of Segments	Seg Type	Cty	Route Type	Route #	Mean AADT	Funct Class	Speed	Lane Width Category	Shoulder Width Category	Lighting	Median Type	TWLTL Category	Median Category	Number of Thru Lanes	Presence of Curb and Gutter	Relative Grade	Sum of Length (miles)	Sum of Crash Code 11	Sum of Crash Code 20	Sum of Crash Code 50	Sum of Crash Code 60	Sum of Lane Width Related Crashes	Total Number of Driveways	Calculated Driveway Density
937		2U	46	4	161	3400	3	55	11	0	N		N/A		0	Y	Level	0.1163	0				0	2	17.1957
938		2U	46	4	161	3400	3	55	11	0	N		N/A		0	Y	Level	0.2833	1				3	0	22.25
939		2U	46	4	161	3900	3	55	11	0	N		N/A		0	Y	Level	0.1577	0				0	0	13.43
940		2U	46	4	161	3900	3	55	11	0	N		N/A		0	Y	Level	0.3505	2				3	9	25.6804
941		2U	46	4	322	4700	4	55	11	2	N		N/A		0	Y	Steep	0.0772	1				1	0	4.02
942		2U	46	7	36	7400	4	45	10	2	N		N/A		0	Y	Level	0.3673	2				6	3	8.1673

APPENDIX C

USABLE AND UNUSABLE LANE WIDTH RELATED CRASH RECORDS BY POLICE JURISDICTION

Jurisdiction	Usable Amount	Unusable Amount	Total Amount	% Unusable
S.C. Highway Patrol, District 1	6002	135	6137	2.20%
S.C. Highway Patrol, District 3	3692	247	3939	6.27%
S.C. Highway Patrol, District 4	1607	72	1679	4.29%
S.C. Highway Patrol, District 5	3331	212	3543	5.98%
S.C. Highway Patrol, District 6	1124	92	1216	7.57%
S.C. Highway Patrol, District 7	1766	48	1814	2.65%
Beaufort County Sheriff's Office	886	74	960	8%
Beaufort Police Dept	283	1	284	0.35%
Bluffton Police Dept	187	6	193	3.11%
Port Royal Police Dept	98	1	99	1%
Sea Pines Security	0	1	1	100%
Hilton Head Plantation Security	1	0	1	0%
Port Royal Plantation Security	2	0	2	0%
Yemassee Police Dept	0	2	2	100%
Horry County Sheriff's Office	11	6	17	35%
Atlantic Beach Police Dept	7	6	13	46.15%
Conway Police Dept	347	23	370	6.22%
Aynor Police Dept	3	25	28	89%
Horry County Police Dept	2	2	4	50%
Loris Police Dept	40	21	61	34%
Myrtle Beach Police Dept	880	64	944	7%
North Myrtle Beach Police Dept	293	62	355	17.46%
Surfside Beach Police Dept	59	4	63	6%
USC - Coastal Carolina Police Dept	22	0	22	0%
Briarcliff Acres Police Dept	1	0	1	0%
Jasper County Sheriff's Office	1	0	1	0%
Hardeeville Police Dept	56	45	101	44.55%
Ridgeland Police Dept	46	30	76	39%
Lexington County Sheriff's Office	50	11	61	18%
Batesburg Police Dept	81	7	88	7.95%
Cayce Police Dept	167	30	197	15.23%
Unknown	3	0	3	0%
Lexington Police Dept	290	2	292	1%
West Columbia Police Dept	475	16	491	3%
Chapin Police Dept	20	0	20	0.00%
Irmo Police Dept	73	16	89	18%

Pelion Police Dept	5	3	8	38%
Pine Ridge Police Dept	8	0	8	0.00%
South Congaree Police Dept	11	5	16	31.25%
Springdale Police Dept	51	2	53	3.77%
Swansea Police Dept	12	4	16	25.00%
Columbia Metropolitan Airport Police Dept	6	0	6	0.00%
Orangeburg County Sheriff's Office	4	4	8	50%
Orangeburg Police Dept	393	11	404	3%
Branchville Police Dept	5	1	6	17%
Cordova Police Dept	1	0	1	0%
Elloree Police Dept	1	0	1	0%
Eutawville Police Dept	1	5	6	83%
Holly Hill Police Dept	9	4	13	31%
North Police Dept	2	0	2	0%
Springfield Police Dept	0	1	1	100%
Santee Police Dept	8	4	12	33%
Vance Police Dept	0	1	1	100%
Pickens County Sheriff's Office	5	8	13	62%
Central Police Dept	38	6	44	13.64%
Clemson Police Dept	124	14	138	10.14%
Easley Police Dept	297	239	536	45%
Liberty Police Dept	38	2	40	5%
Pickens Police Dept	64	8	72	11%
Clemson University Police Dept	35	20	55	36.36%
Norris Police Dept	3	0	3	0%
Richland County Sheriff's Office	39	9	48	18.75%
Columbia Police Dept	2477	33	2510	1.31%
Eastover Police Dept	1	0	1	0.00%
Forest Acres Police Dept	169	17	186	9%
Greer Police Dept	8	76	84	90.48%
Spartanburg County Sheriff's Office	29	4	33	12%
Spartanburg Police Dept	561	178	739	24.09%
Woodruff Police Dept	47	21	68	30.88%
Duncan Police Dept	82	27	109	25%
Chesnee Police Dept	9	0	9	0%
Cowpens Police Dept	9	3	12	25%
Enoree Police Dept	1	0	1	0%
Inman Police Dept	36	24	60	40.00%
Landrum Police Dept	25	5	30	17%
Lyman Police Dept	58	3	61	5%
Pacolet Police Dept	25	3	28	11%
Wellford Police Dept	40	8	48	17%

Greenville/Spartanburg Airport Police Dept	2	5	7	71%
York County Sheriff's Office	6	0	6	0%
Clover Police Dept	47	18	65	27.69%
Fort Mill Police Dept	161	5	166	3.01%
Rock Hill Police Dept	926	8	934	1%
York Police Dept	129	1	130	1%
Tega Cay Police Dept	20	1	21	5%
Winthrop College Police Dept	3	0	3	0.00%
Riverhills Plantation Security	2	0	2	0%
TOTAL	**27,939**	**2,052**	**29,991**	**6.84%**

APPENDIX D

MODEL IVENTORY OF ROADWAY ELEMENTS (MIRE) v. 1.0

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	**Value Added**			
		I. Roadway Segment Descriptors		
I.a. Segment Location/Linkage Elements				
x		County Name	F	R
x		County Code	F	
x		Highway District		
x		Type of Governmental Ownership	F	
x		Specific Governmental Ownership		
x		City/Local Jurisdiction Name		
x		City/Local Jurisdiction Urban Code		
x		Route Number	F	R
x		Route/Street Name	F	
x		Begin Point Segment Descriptor	F	R
x		End point Segment Descriptor	F	R
x		Segment Identifier	F	R
x		Segment Length	F	R
x		Route Signing	F	
x		Route Signing Qualifier	F	
x		Coinciding Route Indicator		
	x	Coinciding Route — Minor Route Information		
x		Direction of Inventory		R
I.b. Segment Classification				
x		Functional Class	F	R
x		Rural/Urban Designation	F	R
x		Federal Aid/Route Type	F	
x		Access Control	F,S	
I.c. Segment Cross Section				
x		Surface Type	S	R
x		Total Paved Surface Width		
x		Surface Friction		
x		Surface Friction Date		
	x	Pavement Roughness/Condition	F,S	
	x	Pavement Roughness Date	F,S	
	x	Pavement Condition (Present Serviceability Rating)	S	

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	Value Added			
	x	Pavement Condition (PSR) Date	S	
x		Number of Through Lanes	F	R
x		Outside Through Lane Width		R
x		Inside Through Lane Width		R
x		Cross Slope		R
x		Auxiliary Lane Presence/Type		R
x		Auxiliary Lane Length		R
	x	HOV Lane Presence/Types	F	
x		HOV Lanes	F	
	x	Reversible Lanes		
x		Presence/Type of Bicycle Facility		
x		Width of Bicycle Facility		
	x	Number of Peak Period Through Lanes	S	
x		Right Shoulder Type	S	R
x		Right Shoulder Total Width		R
x		Right Paved Shoulder Width		R
x		Right Shoulder Rumble Strip Presence/Type		
x		Left Shoulder Type		R
x		Left Shoulder Total Width	S	R
x		Left Paved Shoulder Width		R
x		Left Shoulder Rumble Strip Presence/Type		
x		Sidewalk Presence		
x		Curb Presence		
	x	Curb Type		
x		Median Type	S	R
x		Median Width	S	R
x		Median Barrier Presence/Type	S	
x		Median (Inner) Paved Shoulder Width		
x		Median Shoulder Rumble Strip Presence/Type		
x		Median Sideslope		
x		Median Sideslope Width		
x		Median Crossover/Left Turn Lane Type		
I.d. Segment Roadside Descriptors				
x		Roadside Clearzone Width		

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	Value Added			
x		Right Sideslope		R
x		Right Sideslope Width		
x		Left Sideslope		R
x		Left Sideslope Width		
x		Roadside Rating		R
x		Major Commercial Driveway Count		R
x		Minor Commercial Driveway Count		R
x		Major Residential Driveway Count		R
x		Minor Residential Driveway Count		R
x		Major Industrial/Institutional Driveway Count		R
x		Minor Industrial/Institutional Driveway Count		R
x		Other Driveway Count		R
I.e. Other Segment Descriptors				
x		Terrain Type	S	
x		Number of Signalized Intersections in Segment	S	
x		Number of Stop-Controlled Intersections in Segment	S	
x		Number of Uncontrolled/Other Intersections in Seg	S	
I.f. Segment Traffic Flow Data				
x		Annual Average Daily Traffic (AADT)	F	R
x		AADT Year	F	R
	x	AADT Annual Escalation Percentage		
x		Percent Single Unit Trucks or Single Truck AADT	F,S	
x		Percent Combo Trucks or Combination Truck AADT		
x		Percentage Trucks or Truck AADT		
	x	Total Daily Two-Way Pedestrian Count/Exposure		
	x	Bicycle Count/Exposure		
x		Motorcycle Count or Percentage	F	
	x	Hourly Traffic Volumes (or Peak and Offpeak AADT)		
	x	K-Factor	S	
	x	Directional Factor	S	
I.g. Segment Traffic Operations/Control Data				
x		One/Two-Way Operations	F	R
x		Speed Limit	S	R
	x	Truck Speed Limit		
	x	Nighttime Speed Limit		

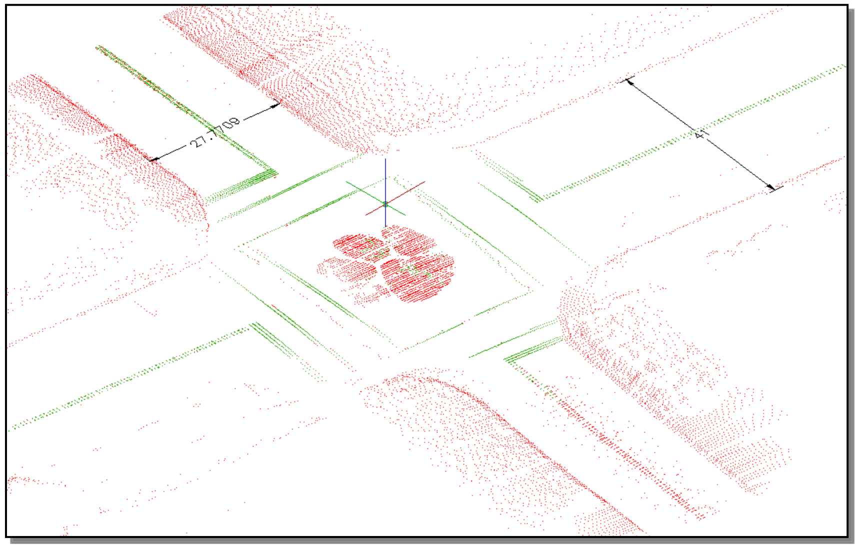
Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	**Value Added**			
	x	85th Percentile Speed		
	x	Mean Speed		
x		School Zone Indicator		
x		On-Street Parking Presence		R
x		On-Street Parking Type	S	R
x		Roadway Lighting		R
x		Toll Facility	F	
x		Edgeline Presence/Width		
x		Centerline Presence/Width		
x		Centerline Rumble Strip Presence/Type		R
x		Passing Zone Percentage		R
I.h. Other Supplemental Segment Descriptors				
x		Bridge Numbers for Bridges in Segment		
		II. Roadway Alignment Descriptors		
II.a. Horizontal Curve Data				
x		Curve Identifiers and Linkage Elements		R
x		Curve Feature Type		R
x		Horizontal Curve Degree or Radius	S	R
x		Horizontal Curve Length		R
x		Curve Superelevation		R
x		Horizontal Transition/Spiral Curve Presence		R
x		Horizontal Curve Intersection/Deflection Angle		
x		Horizontal Curve Direction		
II.b. Vertical Grade Data				
x		Grade Identifiers and Linkage Elements		R
x		Vertical Alignment Feature Type		R
x		Percent of Gradient	S	R
x		Grade Length		R
x		Vertical Curve Length		
		III. Roadway Junction Descriptors		
III.a. At-Grade Intersection/Junctions				
General Descriptors				
x		Unique Junction Identifier		R

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	Value Added			
x		Type of Intersection/Junction		R
x		Location Identifier for Road 1 Crossing Point		R
x		Location Identifier for Road 2 Crossing Point		R
x		Location Identifier for Additional Road Crossing Pts		R
x		Intersection/Junction Number of Legs		R
x		Intersection/Junction Geometry		R
x		School Zone Indicator		
x		Railroad Crossing Number		
x		Intersecting Angle		R
x		Intersection/Junction Offset Distance		
x		Intersection/Junction Traffic Control		R
	x	Signalization Presence/Type		
x		Intersection/Junction Lighting		R
x		Circular Intersection — Number of Circulatory Lanes		
	x	Circular Intersection — Circulatory Lane Width		
x		Circular Intersection — Inscribed Diameter		
	x	Circular Intersection — Bicycle Facility		
Approach Descriptors (Each Approach)				
x		Intersection Identifier for this Approach		R
x		Unique Approach Identifier		R
x		Approach AADT		R
x		Approach AADT Year		R
x		Approach Mode		
x		Approach Directional Flow		R
x		Number of Approach Through Lanes		R
x		Left Turn Lane Type		
x		Number of Exclusive Left Turn Lanes		R
x		Amount of Left Turn Lane Offset		
x		Right Turn Channelization		R
x		Traffic Control of Exclusive Right Turn Lanes		
x		Number of Exclusive Right Turn Lanes		R
	x	Length of Exclusive Left Turn Lanes		
	x	Length of Exclusive Right Turn Lanes		
x		Median Type at Intersection		

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	**Value Added**			
x		Approach Traffic Control		
x		Approach Left Turn Protection		R
x		Signal Progression		
x		Crosswalk Presence/Type		
x		Pedestrian Signalization Type		
	x	Pedestrian Signal Special Features		
x		Crossing Pedestrian Count/Exposure		
x		Left/Right Turn Prohibitions		
x		Right Turn-On-Red Prohibitions		R
	x	Left Turn Counts/Percent		
	x	Year of Left Turn Counts/Percent		
	x	Right Turn Counts/Percent		
	x	Year of Right Turn Counts/Percent		
	x	Transverse Rumble Strip Presence		
x		Circular Intersection — Entry Width		
x		Circular Intersection — Number of Entry Lanes		
x		Circular Intersection — Presence/Type of Exclusive Right Turn Lane		
	x	Circular Intersection — Entry Radius		
x		Circular Intersection — Exit Width		
x		Circular Intersection — Number of Exit Lanes		
	x	Circular Intersection — Exit Radius		
x		Circular Intersection — Pedestrian Facility		
	x	Circular Intersection — Crosswalk Location		
	x	Circular Intersection — Island Width		
III.b. Interchange and Ramp Descriptors				
x		Unique Interchange Identifier		
x		Location Identifier for Road 1 Crossing Point		
x		Location Identifier for Road 2 Crossing Point		
x		Location Identifier for Additional Road Crossing Points		
x		Interchange Type		
x		Interchange Lighting		
x		Interchange Entering Volume		
x		Interchange Identifier for this Ramp		
x		Unique Ramp Identifier		

Priority		MIRE DATA ELEMENTS	HPMS REQD	HSM REQD
Critical	Value Added			
x		Ramp Length		
x		Ramp Acceleration Lane Length		
x		Ramp Deceleration Lane Length		
x		Ramp Number of Lanes		
x		Ramp AADT		
x		Year of Ramp AADT		
x		Ramp Metering		
x		Ramp Advisory Speed Limit		
x		Roadway Type at Beginning Ramp Terminal		
x		Roadway Feature at Beginning Ramp Terminal		
x		Location Identifier for Roadway at Beg Ramp Terminal		
x		Location of Beg Ramp Terminal Relative to Mainline		
x		Roadway Type at Ending Ramp Terminal		
x		Roadway Feature at Ending Ramp Terminal		
x		Location Identifier for Roadway at End Ramp Terminal		
x		Location of End Ramp Terminal Relative to Mainline		

Operational and Safety Characteristics of Lane Widths



PHASE B

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1 INTRODUCTION

The main goal of this two-phase study is to determine the influence that flexible lane width standards have on the safety and operation of roadways in South Carolina. In 2011, Phase A of this research was conducted using field studies to discern the effect on effects of lane widths on safety. Throughout Phase A, several limitations were discovered as the project progressed. As an observational study, data was limited based on the availability of site specific parameters and what could be observed in the field. It is no surprise that the majority of sites fell within a small range of allowable limits set forth in the Highway Design Manual. Thus, the study of flexible lane widths was limited by the lack of variable lane width combinations found in the field. Due to such limitations, it was difficult to obtain and analyze an adequate sample of roadways regarding the desired lane and shoulder width attribute combinations. Due to these limitations, it became apparent that to fully investigate the effects of variable lane widths, a Phase B driving simulator study needed to take place. By using a driving simulator, controlled tests can be performed and designed for the lane and shoulder width combinations that could not be analyzed in the field in Phase A. The addition of this study further identified how South Carolina will benefit from implementing more flexible lane width standards.

Based on the following objectives, the aim of this study is to ultimately provide and build upon the design recommendations made in Phase A pertaining to the selection of standard lane and shoulder widths for new projects. The objectives for this experiment were multiple, including determination of the:

1.) Effect lane and shoulder width combinations have on driver performance.
2.) Effect of curves on lane position for various lane and shoulder width combinations.
3.) Operational performance (gap acceptance and maneuverability) of TWLTLs for minimum and maximum widths.

To incorporate all of these objectives into one study, three scenarios were designed. Three different lane and shoulder width combinations were tested on a rural curvy two-lane undivided highway. These combinations included a 12 ft. roadway with no paved shoulder, a 12ft. roadway with a 2 ft. paved shoulder and a 10 ft. roadway with a 2 ft. paved shoulder. These combinations were implemented to test their effect on the driver's choice of lateral position. Analyses for the TWLTLs were conducted on both a 3T and 5T. The TWLTL widths were 12, 14 and 16 ft. Participants were instructed to make left turns out of a development/ driveway into the TWLTL. Analyses were conducted to determine if the width had any effect upon gap acceptance. Operational analysis of the TWLTL was also examined based on how participants maneuvered in the center lane as a function of the lane width.

The remainder of this document is composed of numerous chapters that expand upon the various aspects of this study. Chapter 2 consists of a comprehensive literature review of previous driving simulator studies that evaluated the effect of lane width on driving behavior. Following the literature review is Chapter 3 which provides a detailed description of the methods used to perform the study. Results from the study are presented in Chapter 4 followed by a discussion section. This chapter provides findings regarding the effects of lane and shoulder width combinations on lane position and out of lane encroachments, as well as the effects of the TWLTL width on gap acceptance and maneuverability. Lastly, Chapter 5 consists of final conclusions regarding the objectives that were tested and recommendations for SCDOT. Appendices are also attached to expand upon findings and processes that were used during the study.

2 LITERATURE REVIEW

While field studies are critical in learning about various roadway treatments, the diversity of environments and driver characteristics often cause difficulty in conducting comparative research. To be specific, adverse weather and unaccounted traffic congestion can easily interfere with a study. Due to the ability to control the test environment driving simulators have proven to be an influential tool providing additional avenues for research (Hein, 2007). The unique ability to design specific scenarios has increased our ability to explore and learn more about driving behavior, driver responses, user performances and training. Simulators allow researchers to emulate real life roadway conditions in a safe and practical manner. As stated by Van Der Horst et al. (2011) “Systematic control over the experimental conditions with respect to road design elements, traffic management, other traffic, and environmental conditions makes human factors research in a driving simulator attractive, efficient and effective.” After performing their driving simulator study Godley et al. (2001), also stated that simulators enable “Experimental control, efficiency, expense, safety and ease of data collection.” For these reasons, the research team chose to conduct an experiment for lane width conditions that don’t currently exist in significant numbers in the field.

Despite the beneficial use of reducing risk and increasing safety, simulators also have drawbacks- including potential simulator sickness. This syndrome is commonly perceived as motion sickness as both conditions express similar side effects such as nausea, headaches, sweating, disorientation and vomiting (Brooks et al., 2010) .While driving a simulator, it is common for the body’s vestibular senses to perceive the discontinuity between the visual and physical effects, thus causing these symptoms to occur (Brown, 2012). Simulator sickness can be detrimental to an experiment by undermining the effectiveness of training and causing various participants to drop out of the study (Brooks et al., 2010) (de Winter et al). Additional limitations and challenges of driving simulators focus on fidelity and validity. The quality of simulator use is often determined by these two aspects (Riener, 2011). Fidelity refers to the level of realism expressed by the simulation, while validity is “the degree to which behavior in a simulator corresponds to behavior in real-world environments under the same conditions (Riener, 2011).” Studies by (Engström et al., 2005) expressed a relationship between these two variables in which high fidelity simulators provide a more realistic environment, thus producing results of higher validity in comparison to a low fidelity simulator. Hein (2007) studied the costs and benefits between the two types of simulators and field studies with results provided in Table 2-1. As shown, the high fidelity simulation exceeds on the road studies in all categories except degree of realism. Low fidelity simulators also exceed on the road studies in most of the categories excluding degree of realism and ability to study range of traffic conditions.

Table 2-1: Driving simulation and on the road studies comparison (Hein, 2007)

Benefits/Costs	Low-Fidelity Simulation	High-Fidelity Simulation	On-the-Road Studies
Ability to study relevant driver behaviors	Medium-High	High	Medium
Ability to study range of highway geometrics	High	High	Medium
Ability to study range of traffic conditions	Medium	High	Medium
Control over experimental conditions	Medium-High	High	Medium
Degree of realism	Medium	Medium-High	Very High
Relative cost	Medium	High	High
Risk to driver	Very Low	Very Low	Low-Medium

Based on the parameters of the study, funds, and availability of resources the desired fidelity may be hard to obtain. The second quality-defining parameter and constant challenge of simulator use is validity. Validity is the premise in which findings from the simulated environment can be applied to the real world. It can be broken down into two categories, physical validity and behavioral validity. Physical validity is represented as the degree in which the simulator's visual components, dynamics and layout replicate the real world hence, fidelity (Brown, 2012; Blaauw, 1982). Behavioral validity measures the similarity between driving behavior in the simulator compared to behavior in the real world. The validity of a study can further be defined as absolute or relative. Research suggests that validation is best tested by comparing driving in the simulator to a real car while performing tasks that are extremely similar for both conditions (Blaauw, 1982). When comparing variables between the simulated and real world environment it is possible to achieve absolute or relative validity. Absolute validity is established if the numerical values between the two systems are the same. Relative validity is expressed when "the differences found between experimental conditions are in the same direction, and have a similar or identical magnitude on both systems (Godley et al., 2002)." Results from driving simulators are considered useful if relative validity is achieved (Törnros, 1998).

In 1998 Wade and Hammond conducted a study testing the relative validity of lateral lane position measurements. In the study 26 participants drove on simulated and real-world rural roadways. By using several vehicle performance measures, kinematic variables and a questionnaire comparing the two environments the team was able to conclude relative validity based on lateral position.

2.1 Lane/Shoulder Width and Road Geometry

One of the main objectives of this study was to evaluate the effect that lane width, shoulder width and roadway geometry have on driver perception and behavior. While roadway design is typically associated with accident rate, there are very few studies that investigate the effect roadway design features have on driver behavior. A specific attribute affected by the driver's perception of the road's safety is speed. Several studies suggest that narrow roads and lanes will reduce driver speed and produce safer driving behavior (Shinar, 2007). Shinar predicted that drivers assess narrower roads as being more dangerous thus causing the driver to slow down to avoid accidents and risky situations. De Waard et al. (1995) also proposed that narrower roadways require more mental effort for the driver to maintain lane position. Contrary to these findings, other studies indicate a negative effect between narrow shoulders and safe driving behavior. A study by Dewar and Olson (2007) found that narrow shoulders on two-lane roads caused drivers to steer closer to the center of the road increasing the risk of a head-on collision.

Another characteristic that can affect driver behavior is the roadway geometry. To be specific, it requires more effort from the driver to stay in the lane while driving through curves. The limited visibility when encountering a curve limits the driver's ability to perceive the route ahead which increases uncertainty (Martens et al., 1997). It is often difficult to evaluate the effects of roadway geometry alone due to the extreme influence that lane and shoulder width play on the driver's perception. To help understand and distinguish such effects many researchers have started to perform driving simulator studies.

2.2 Lane Keeping Studies

Green et al. (1994) used the UMTRI driving simulator to test the relationship between roadway geometry and driver performance. In this study eight participants drove a series of six winding road segments with varying sight distance and widths ranging 15 to 24 ft. Results from the study shown in Figure 2-1 revealed significant effects on the standard deviation of lane positioning due to road width. It was also evident that the standard deviation of lateral position increased as the road became wider and decreased as sight distance increased.

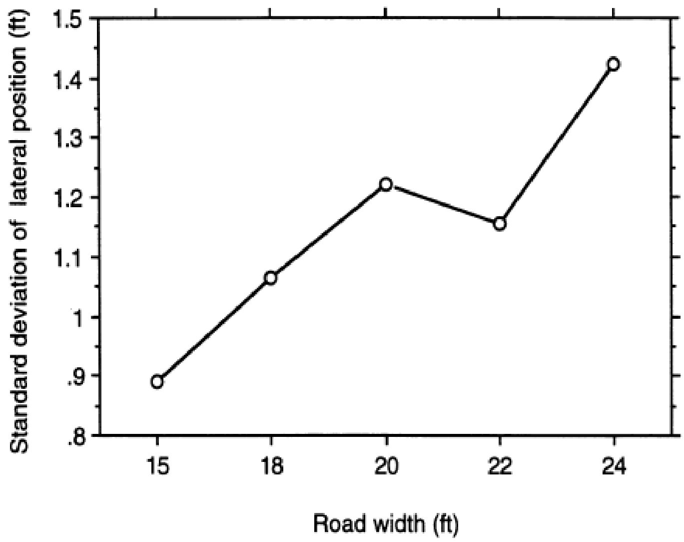


Figure 2-1: Effect of lane width on standard deviation of lane position (Green et al., 1994)

In 2011, Dijksterhuis et al., used a driving simulator to observe lane position across four different lane widths: 3.00 m, 2.75 m, 2.50 m, and 2.25 m. Subjects were also exposed to high and low densities of oncoming traffic while driving each lane width section within the scenario. Each section was designed identically on rural roads that consisted of 85% curves with 382 m radii. The remaining 15% of the roadway was composed of straight sections and intermittent towns that separated the four sections of varying roadway widths. Results showed no significance between the different levels of lane width and oncoming traffic density. Marginal significance was found between the 3.00 m and the 2.50 m lane width conditions and the 2.75 m and 2.50 m conditions. Although the lane width did not affect lane position, the presence of traffic did produce obvious changes in lane position (Figure 2-2). With low traffic levels, the vehicle is nearly centered in the lane; when traffic levels are high, the vehicle shifts roughly a third of a meter toward the outside edge (Figure 2-3). The high traffic portion of this figure shows that participants drove over the lines the most while driving in the 2.25 m lane width. As the lane width increased participants' lane keeping performance increased.

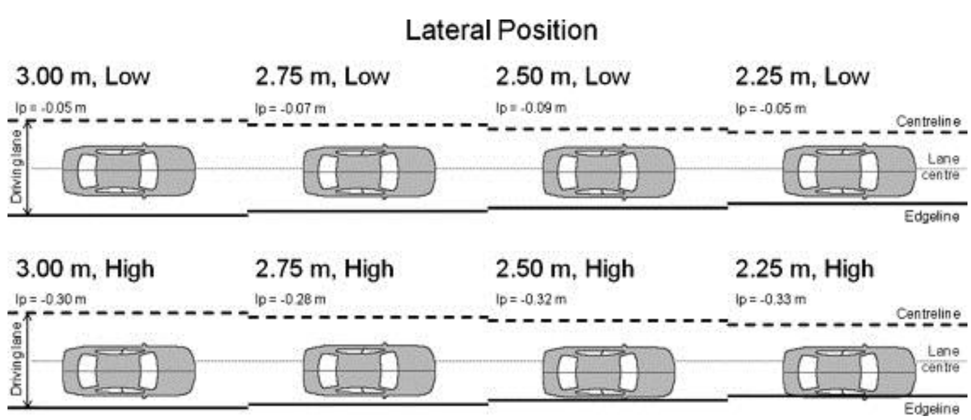


Figure 2-2: Mean lateral position of the vehicle in the lane (Dijksterhuis et al., 2010)

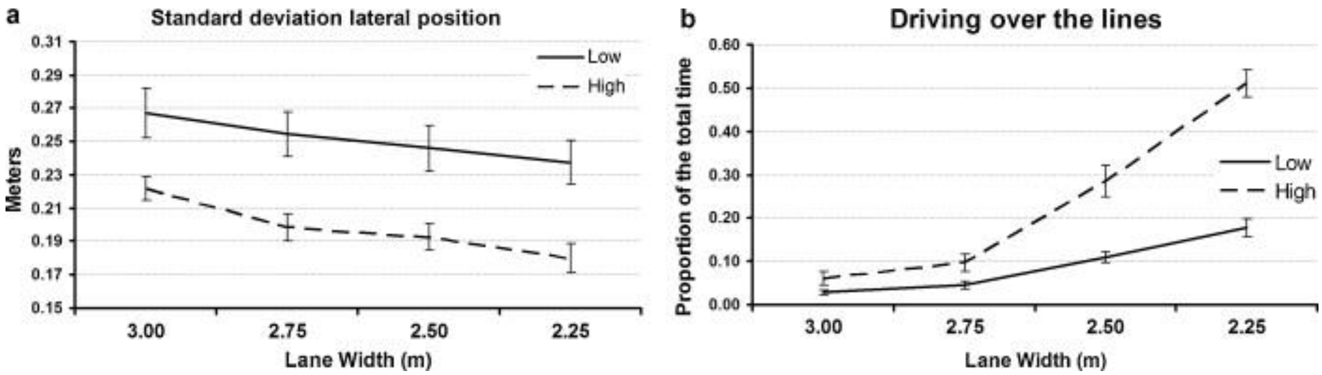


Figure 2-3: Lane Width and Lane Keeping (Dijksterhuis et al., 2010)

A study conducted by Ben-Basset and Shinar (2011) evaluated lane wandering as a function of shoulder width and presence of guardrail. The paved shoulder widths evaluated were 0.5, 1.2 and 3.0 m. The roadway geometry in each scenario included right and left sharp and shallow curves. Curve radii were set at 80 m and 380 m respectively. Roads in the scenario were four-lane divided highways with two 4.5 m lanes in each direction. Results from the study found an extreme deviation in variance for all three shoulder widths when driving sharp left turns. Analysis also revealed significant effects of shoulder width on the average lane position. Values for lane position were determined as the distance of the center jersey to the center of the vehicle as shown in Figure 2-4.

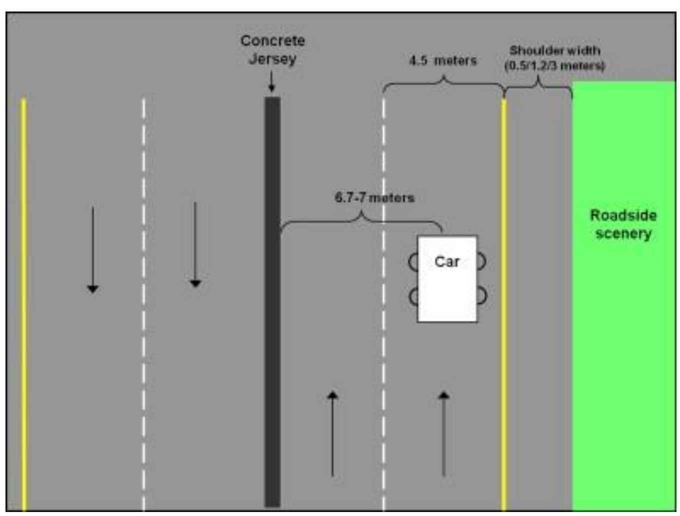


Figure 2-4: Lane position (Ben-Bassat and Shinar, 2011)

Subjects drove significantly closer to the left lane with a 0.5 m shoulder than the 1.2 and 3.0 m shoulders. Average lane position values for these widths were 6.9, 7.1 and 7.3 m respectively. From these results it is evident that as the road shoulder became wider the participants gravitated more towards the middle and right edge of the lane. The trend can be seen in Figure 2-5. Additional analysis compared the standard deviation of lane position against road geometry. From Figure 2-6 it is evident that the roadway geometry had a significant impact on the driver's ability to keep in the center of the right lane. The large standard deviation of lane position for the sharp left turn indicates that the participants were wandering along the lane and may have veered off the road.

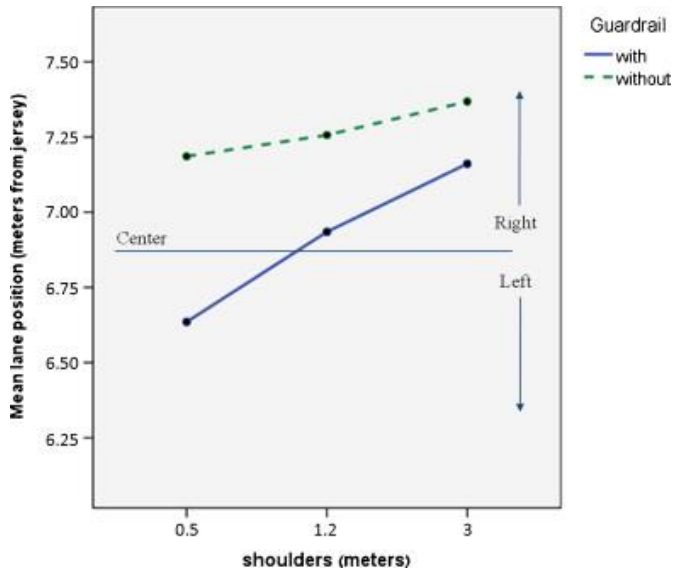


Figure 2-5: Effect of shoulder width on mean lateral position (Ben-Bassat and Shinar, 2011)

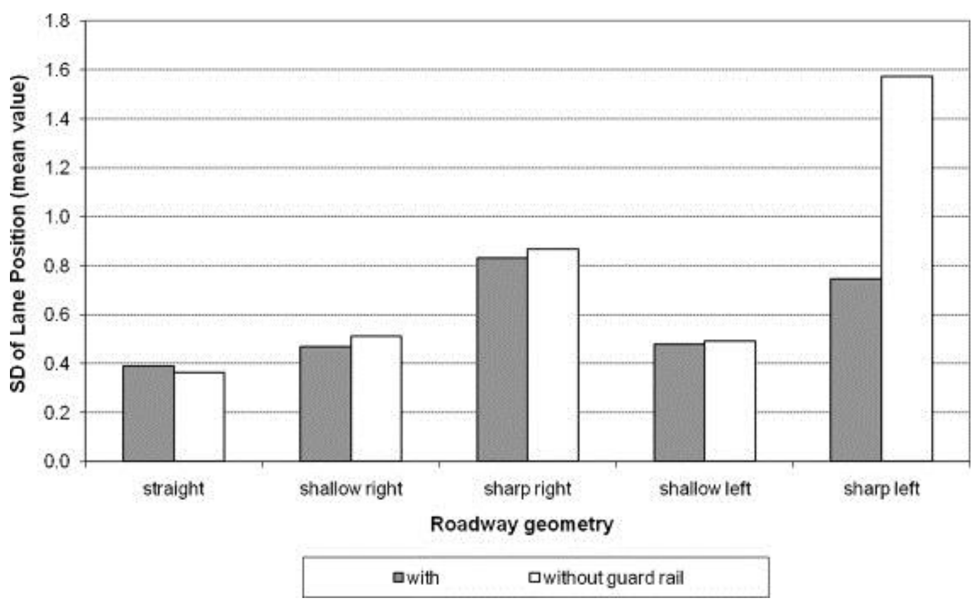


Figure 2-6: Effect of roadway geometry on lane position standard deviations
(Ben-Bassat and Shinar, 2011)

2.3 Gap Acceptance

Other essential aspects of this paper focus on the operational performance of two-way left turn lanes (TWLTL) and gap acceptance. Gap acceptance as defined by the Highway Capacity Manual (HCM) 2010 is "The process by which a driver accepts an available gap in traffic to perform a maneuver." This behavior is often seen at a two-way stop- controlled intersection (TWSC). A TWSC intersection is one of the most commonly used unsignalized intersections in the United States (Kittelson and Vandehey, 1991). They are composed of a "major" street that is uncontrolled and a "minor" street that is controlled by stop signs (Nabaee, 2011); (HCM, 2010). In this setting, gap acceptance behavior is expressed when a vehicle on the minor street needs to cross the major street and when a vehicle must make a left turn that crosses the path of the opposing movement. This concept is also seen on midblock arterials when a driver must make a left turn out of a development into a two-way left turn lane. All of these cases test the driver's ability to perceive a stream of dynamic oncoming traffic and evaluate the availability and usefulness of the gaps to safely maneuver across through travel lanes(Zohdy et al., 2010),(Nabaee, 2011). Gap also referred to as headway is further defined by the HCM (2010) as the elapsed time between two successive vehicles as they pass a specific point on the roadway measured from the same feature of both vehicles. The minimum gap that a driver will accept is commonly known as the critical gap. It is assumed that drivers would accept gaps equal to or larger than the critical gap and reject gaps that are less than the critical gap (HCM, 2010). This parameter is typically used to determine the safety and operational performance of TWSC intersections (Nabaee, 2011).

While gap acceptance is a common behavior many factors affect the drivers' decision making process in deeming a gap acceptable. External factors include time of day effects, type of intersection control, intersection geometry, driver's sight distance, and speed of opposing vehicles (Zohdy et al., 2010). Studies have also led to results indicating that driver characteristics age and gender influence a driver's gap acceptance behavior (Moussa et al., 2012).

In 2007, a driving simulator study was conducted by Yan et al. to determine the effects of age and gender on drivers' left turn gap acceptance behavior at a two-way stop controlled intersection. The equipment used throughout the experiment was a high fidelity driving simulator composed of five channels providing 180 degree field of view, a motion base and Saturn Sedan cab. The study tested a total of 63 participants with defining age categories of young (20-30), middle (31-55) and old (56-83). Vehicle gaps in two major street speed scenarios (Figure 2-7) were arranged in a uniformly ascending order from 1 to 16 seconds.

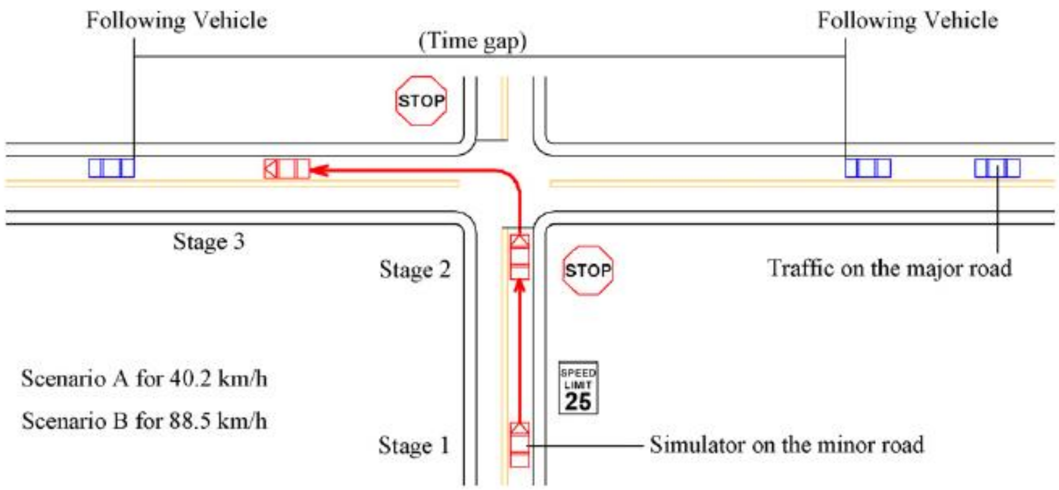


Figure 2-7: Traffic scenario design for left-turn gap acceptance (Yan et al., 2007)

Results indicated that older drivers accepted larger gaps than middle age and young drivers. Average gap values were 7.94 s, 6.20 s, and 6.29 s respectively. No significant difference between young and middle age drivers was found. Gender results showed that male drivers accept smaller gaps at an average of 6.38 s than females with an average gap of 6.93 s. Such findings lead Yan et al. to suggest that female drivers and older drivers are more conservative.

Another study that evaluated left-turn maneuvers at a two-way stop controlled intersection was conducted by Moussa et al. (2011). This study integrated simulation with a field study through the use of an augmented reality vehicle system, “ARV.” The system is a tool installed in a vehicle that allows the driver to see an augmented video where virtual objects can be added to the real-world view in real time. A total of 44 participants drove one scenario where they made a left-turn maneuver at a two-way stop controlled intersection. Results revealed that all participants accepted gaps in a range of 4 to 9 s. Older drivers in the study accepted larger gaps averaging 7.36 s compared to younger drivers who averaged 6.20 s gaps. Agreeing with Yan, Moussa’s findings suggest that older drivers are the most conservative (Yan et al., 2007). The results also found no significance between gender and gap acceptance. The frequencies of gaps taken throughout the study are expressed in Figure 2-8.

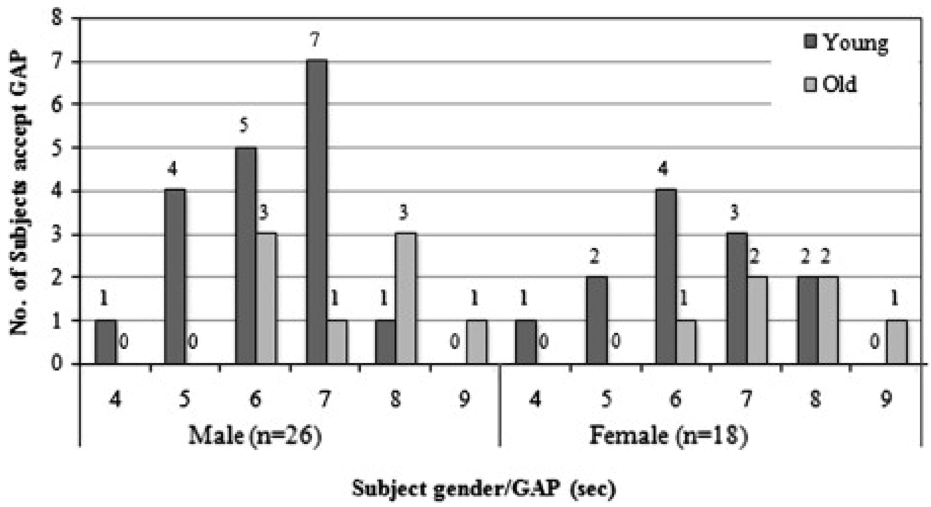


Figure 2-8: Gap acceptance as a function of subject's gender and age (Moussa et al., 2012)

Due to variation in external factors, the critical gap for a specific maneuver can fluctuate greatly. It has also been found that waiting time can affect a driver's gap acceptance behavior. As the waiting time increases the driver will become more inclined to take the risk of accepting a smaller gap. Results from Xiaoming et al's study found that after a long wait time many drivers would accept shorter gaps that they had previously rejected.

2.4 Two-way Left Turn Lane

As previously stated, intersection geometry can have a major impact on gap acceptance behavior. A specific instance is when the major street has a storage area, otherwise known as a TWLTL. The TWLTL is a separate lane used for left turning vehicles and property access. They are typically the center lane of a five and three lane roadway, as seen in Figure 2-9 below.

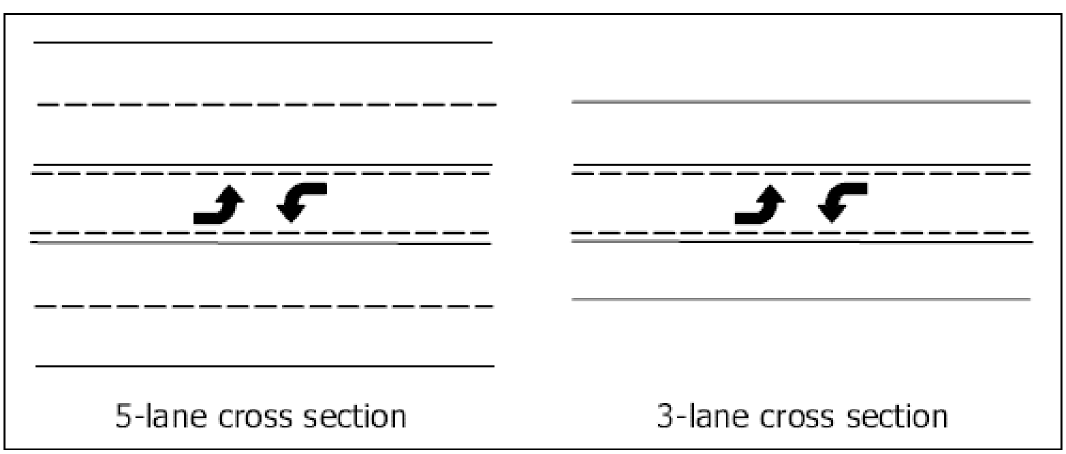


Figure 2-9: Roadway configuration (Manual, 2004)

In these settings, drivers that want to make a left turn experience two-stage gap acceptance. During the process, drivers will first assess and use gaps in the near side major street traffic and wait in the TWLTL until they find another acceptable gap in the far-side major street traffic stream (HCM, 2010). Due to the presence of a central storage place, drivers on the minor street do not need coinciding gaps in both major directions thus increasing the capacity for minor movements (Brilon and Wu, 2003) Often TWLTLs are implemented on urban and suburban roadways where mid-block entrances are too close for turn lanes or when the percentage of turning volumes is high causing congestion for through lanes. Studies suggest that adding a TWLTL on roadways under these conditions can result in improved safety and capacity (Manual, 2004). A study conducted in Minnesota between 1991 and 1993 revealed that three lane roadways with a TWLTL are about 27% safer than a four lane undivided roadway and a five lane roadway with a TWLTL is approximately 41% safer than a four lane undivided roadway (Manual, 2004). Lane width guidelines for these facilities typically vary by state. Ranges depicted in *A Policy of Geometric Design of Highways and Streets,* “AASHTO Greenbook,” include 10 to 12 ft. for urban/suburban arterials and 10 to 16 ft. for urban/suburban collectors. While there are many studies that evaluate the change in the operational performance of the roadway through the addition of a TWLTL very few have focused on the effects produced by the TWLTL width. The lack of research in this area further encourages the necessity for further studies. To gain more knowledge the simulator study performed in this paper analyzed the effect that varying TWLTL widths had on driver maneuverability and gap acceptance.

3 METHODOLOGY

The purpose of this Phase B study was to evaluate three main objectives:

1. Effect of lane and shoulder width combinations on driver lateral-position and lane-keeping performance.
2. Effect of curves on lane position for various lane and shoulder width combinations.
3. Operational performance (gap acceptance and maneuverability) of TWLTLs for minimum and maximum widths.

Treatment effects were compared through the use of a driving simulator. The study was conducted through a series of five different tasks: 1.) Determine study procedures and obtain IRB approval 2.) Scenario Development 3.) Scenario Review 4.) Full study 5.) Data Analysis. The first task of the study included outlining the experimental procedure for testing subjects. Prior to using the simulator it was imperative to ensure that all requirements for the experiment were met and to gain approval from Clemson's Institutional Review Board for the testing of human subjects. The second task consisted of scenario development. In this part of the study, all experimental parameters were implemented into the design of three driving simulator scenarios. These encompassed three lane width and shoulder width combinations and six two-way –left turn lane (TWLTL) treatments. Once all of the scenarios were designed, sample tests were conducted to test the various capabilities and limitations of the simulator and examine the measured variables of lane position, speed, gap acceptance and vehicle heading. For these sample experiments various South Carolina Department of Transportation steering committee members and graduate students were tested and produced feedback on the scenario layout. After making several alterations to improve the experiment, the full scale study commenced. In this task, subjects drove five adaptation scenarios to acclimate them to the simulator followed by the three treatment scenarios. During the full scale study, data was collected for all participants, thus leading to the final task of data analysis.

The next four sections will provide extensive detail on the materials used, project details, the scenario layout, participants and data analysis procedure.

3.1 Materials

This experiment was conducted through the use of Clemson University's driving simulator located in Brackett Hall (Figure 3-1). The simulator is a high performance and high fidelity product produced by Drive Safety. It has five projection screens and three configurable rear view mirrors. The simulator has a partial Ford Focus cab with standard driver controls and a full width front interior. The car functions with an automatic transmission and has a 3-D audio system to incorporate the sounds of the engine and traffic noise to the driving experience. The simulator also sits on a platform enabling longitudinal movement.

The software for the simulator is composed of three different components: Vection, Dashboard and the HyperDrive Authoring Suite. Vection is the component that runs the simulation. The HyperDrive Authoring Suite is a windows-based software package that enables the ability to design scenario layouts and manipulate various variables relating to traffic, road side entities, and community types amongst others. The software can also collect data on 25 user defined variables pertaining to lane position, acceleration, deceleration, heading and more. Lastly, Dashboard is the interface that bridges the design aspect of HyperDrive to a virtual reality. It transfers the newly developed scenarios in HyperDrive to the driving simulator, thus allowing the scenarios to be driven in the simulator.

Figure 3-1: Drive Safety DS600 driving simulator

3.2 Project Details & Layout

The main objectives for this study were to test and analyze the effect of lane and shoulder width combinations on driver performance, to test the effect of curves on lane position for various lane/shoulder width combinations, and to test the operational performance of TWLTLs for minimum and maximum widths. The first two objectives were accounted for in the beginning of the three scenarios. Each scenario started with a 1.5 mile rural curvy two-lane highway. The roadway consisted of numerous curves and straight sections. Figure 3-2 shows a sample straight section. Specific curve radii and roadway layout for the scenarios can be seen in Figure 3-3 and Table 3-1. Along this section, each scenario had different lane/shoulder width combinations. These combinations included 12 ft. lanes and no shoulder for Scenario 1, 12 ft. lanes and a 2 ft. paved shoulder for Scenario 2 and 10 ft. lanes with a 2 ft. paved shoulder for Scenario 3. The speed limit for each roadway was set at 50 miles per hour. Lane position and speed data was collected for this section to analyze the number of right and left lane edgeline touches and determine percent time out of lane per curve. To reduce the effect of speed on the measured variables a 10 miles per hour threshold was allowed. An audio recording was programmed to say “Increase your speed” if the driver drove below 45 miles per hour and “Slow Down” if the driver exceeded 55 miles per hour.

Figure 3-2: Rural two-lane undivided roadway

Table 3-1: Curve radii per scenario for rural section

Scenario 1 and 2		
Curve	**Radius (m)**	**Radius (ft)**
1	418.0	1371.4
2	378.0	1240.2
3	416.8	1367.5
4	352.7	1157.2
5	375.9	1233.3
6	604.3	1982.6
7	362.3	1188.6

Scenario 3		
Curve	**Radius (m)**	**Radius (ft)**
8	1665.0	5462.6
9	451.6	1481.6
10	344.0	1128.6
11	296.0	971.1
12	370.0	1213.9
13	654.0	2145.7

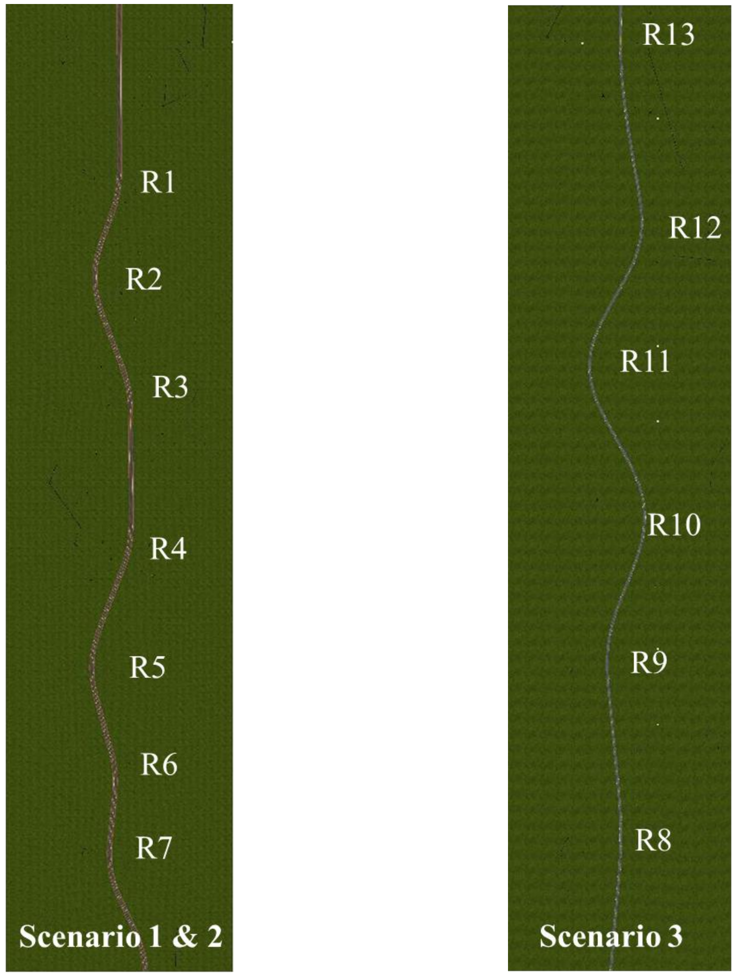


Figure 3-3: Rural roadway geometry

Following the curvy section was a continuous town segment where subjects made a total of four left turns from driveways into two-way-left turn lanes. Gap acceptance and vehicle position were measured on both a three lane roadway with a center two-way left turn lane (3T) and a five lane roadway with a center two-way left turn lane (5T). Two of the left turns were made on a 3T roadway, and the remaining two were made on a 5T roadway. Images of these roadways are expressed in Figures 3-4 and 3-5. Both roadway geometries were tested with TWLTL widths of 12, 14 and 16 ft., creating a total of six combinations. Scenario 1 tested TWLTL widths of 12 ft. for the 3T turns and 16 ft. for the 5T turns. Scenario 2 tested 16 ft. for the 3T turns and 14 ft. for the 5Ts while Scenario 3 tested 14 ft. for the 3Ts and 12 ft. for the 5Ts. Overall, each scenario had the same layout containing a rural curvy section, two 3T and two 5T sections. A comprehensive summary and scenario layout image is shown in Figure 3-6.

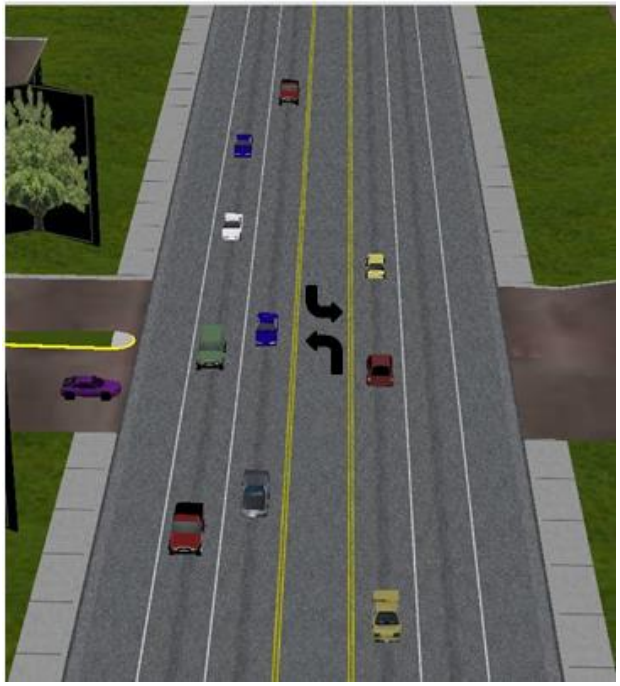


Figure 3-4: 5T section in HyperDrive

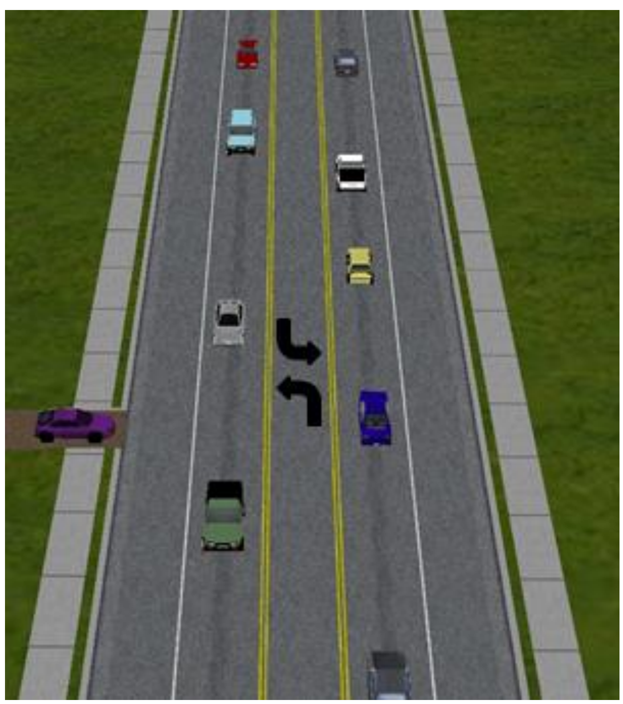


Figure 3-5: 3T section in HyperDrive

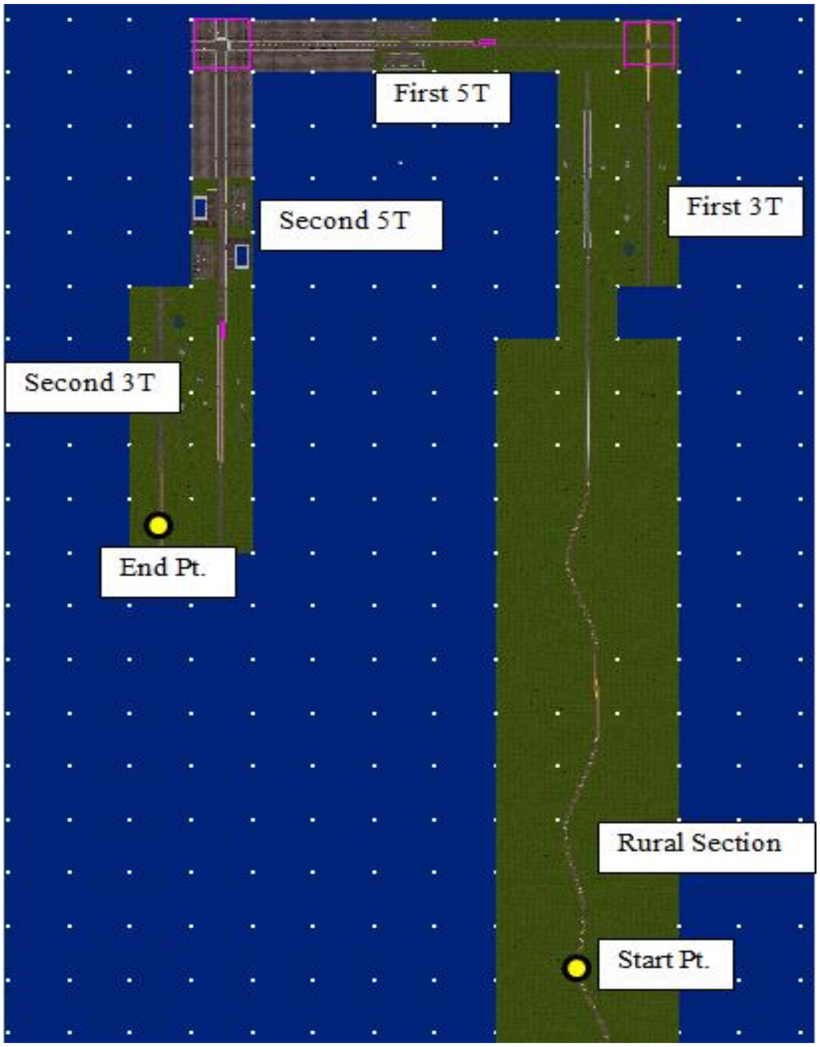


Figure 3-6 : Complete scenario layout in HyperDrive

Scenario 1

- Rural 3 mile section (12’ lane, no shoulder)
- 3T Section (12’ lanes, 12’ TWLTL)
- 5T Section (12’ lanes, 16’ TWLTL)

Scenario 2

- Rural 3 mile section (12’ lane, 2’ shoulder)
- 3T Section (12’ lanes, 16’ TWLTL)
- 5T Section (12’ lanes, 14’ TWLTL)

Scenario 3

- Rural 3 mile section (10’ lane 2’ shoulder)
- 3T Section (12’ lanes, 14’ TWLTL)
- 5T Section (12’ lanes, 12’ TWLTL)

3.3 Adaptation Scenarios

To familiarize the participants with the driving simulator's handling, five adaptation scenarios were conducted. The first scenario taught the driver the basics of lane position in the simulator. For this session, the driver drove on a straight road with a speed limit of 45 miles per hour. In the middle of the front screen there were five dots that would light up indicating the vehicle's lane position: far left, left, center, right, and far right. Participants were given the opportunity to drive this scenario twice for thirty seconds to test and understand the different lane boundaries within the simulator. An image of this can be seen in Figure 3.7.

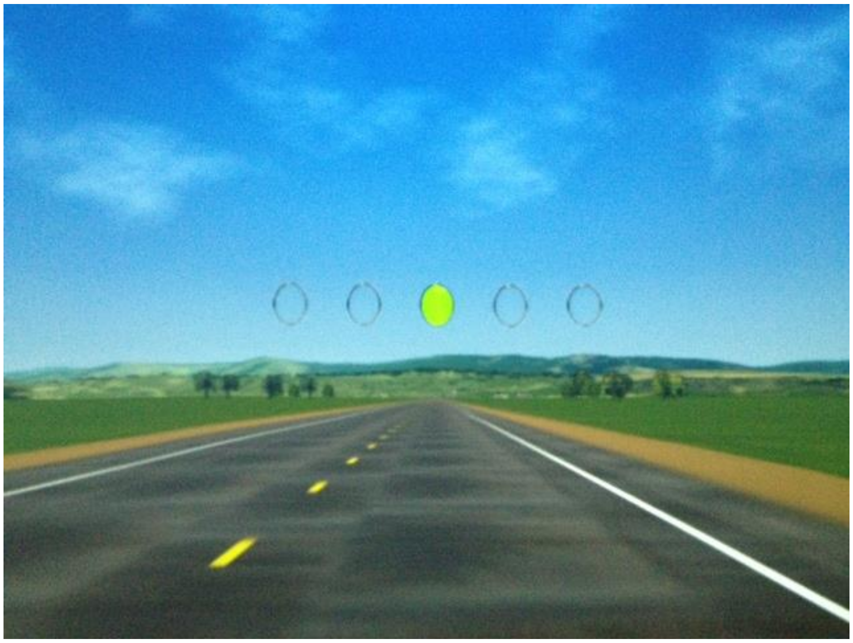


Figure 3-7: First adaptation scenario- lane keeping

The second adaptation scenario practiced lane keeping on a curvy road with a speed limit of 45 miles per hour. For this session, the driver did not have the aid of the five dots on the screen indicating their lane position. The participants drove this scenario for a full sixty seconds, and the number of right and left edge touches during this time period were recorded. The third scenario practiced stopping. Throughout this session, the drivers had to make a series of five stops. Data for this scenario showed how close the car was to the stop bar. A participant performed well if an average of plus or minus two feet was maintained. In the fourth adaptation scenario, the driver had to complete six left turns. The purpose of this scenario was to familiarize the participants with the speed and maneuverability required to perform a left turn. The fifth and final adaptation scenario led the driver to make four right turns. Not only were these scenarios essential in familiarizing participants with the driving simulator, they also helped identify subjects prone to simulator sickness.

3.4 Full Scale Study

3.4.1 Participants

The full scale study was conducted for a total of 60 participants. From this total, two age groups were identified. The first age group consisted of 40 young drivers between the ages of 18 to 34. The second group consisted of 20 participants within the age range of 35+ years. All participants were compensated fifteen dollars per hour for the time they spent participating in the study. The max amount one participant could earn was thirty dollars. Participants were recruited by advertising flyers and word of mouth. Table 3-2 shows a summary of all the participants that were tested, including those who were unable to complete the study due to simulator sickness. A complete listing of participants is provided in Appendix E.

Table 3-2: Participant data

	Female	Male	Total
Young	20	20	40
Middle	6	14	20
Dropout- Simulator Sickness	6	6	12
Total # of Participants	-	-	72
# Participants Data used	-	-	60

3.4.2 Driving Scenario Design

To design the three experimental scenarios various steps were undertaken. One of the first steps included determining the different lane and shoulder width combinations and TWLTL widths to be tested. To do this, it was important to become familiar with the driving simulator's program, HyperDrive Authoring Suite where the scenarios were created. This involved learning the functions of the program and identifying useable tiles in its library. The tiles were small roadway segments of preset cross-section that would be placed together to form the desired scenario.

It was decided that the first part of each scenario would be the rural curvy two-lane highway section in which the various lane and shoulder width combinations would be tested. Based on the current SCDOT Highway Design Manual guidelines and the availability of lane width tiles within the simulator's library, both 12 ft. and 10 ft. lanes were used in this section. The shoulder widths chosen for these lane widths were either a 2 ft. paved shoulder or no shoulder. Of the sites with shoulders in Phase A of this study, most either had no paved shoulder or a 2-ft. paved shoulder.

Table 3-3: Rural undivided highway variables-Phase A (Bauman and Jordan, 2012)

Independent Variable	Coefficient	Number of Segments
Lane Width (ft)	c_{10}	53
	c_{11}	161
	c_{12}	109
Shoulder Width (ft)	d_0	222
	d_2	101
Speed Limit (mph)	e_{35-}	11
	e_{40-45}	86
	e_{50-55}	226
Driveway Density (Driveways/Mile)	f_{Low}	281
	f_{Med}	42
Moderate Grade	g	68

This produced the roadway combinations of 12ft lanes and no paved shoulder for Scenario 1, 12 ft. lanes with a 2 ft. paved shoulder for Scenario 2, and 10 ft. lanes with a 2 ft. paved shoulder for Scenario 3. To perfect this section of the scenarios a great deal of work was done. One curvy rural tile had 6 ft. shoulders on either side of the roadway. To create no shoulder for Scenario 1 and a 2 ft. shoulder for Scenario 2 various small grass tiles had to be overlapped over the existing large shoulder. Since there was no 10 ft. rural curvy tile, this tile had to be custom made by the designer of Drive Safety. The specific curve start and end points and dimensions are located in Appendix B. The next step taken to further evaluate this portion of the scenario was to determine the speed of the roadway. It was assumed that the rural tile in each scenario had a superelevation value of 6%. Based on the minimum radius, a design speed of 50 mph was determined from the Policy of Geometric Design of Highways and Streets. The speed limit was set at 50 mph which was also the predominant observed posted speed for these types of roadways in Phase A.

The next part of each scenario was the development of the town segments where participants drove a series of four left turns into TWLTLs. For this step it was important to choose TWLTL widths that would provide acceptable comparative data. Based on the available tiles in the HyperDrive library and the distribution of TWLTL widths that were measured in the field during Phase A of this study, TWLTL widths of 12, 14 and 16 ft. were used. The distributions of TWLTL widths for 3T and 5T roadways from Phase A of the study can be seen in Figures 3-8 and 3-9. Several of these tiles had to be custom designed from DriveSafety.

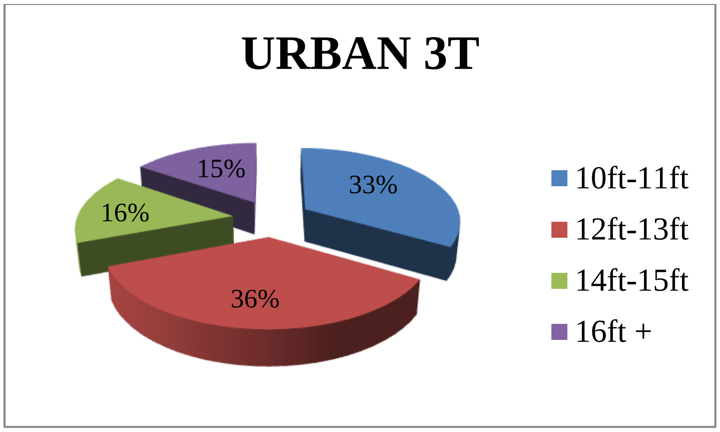


Figure 3-8: Distribution of urban 3T TWLTL widths from Phase A of study

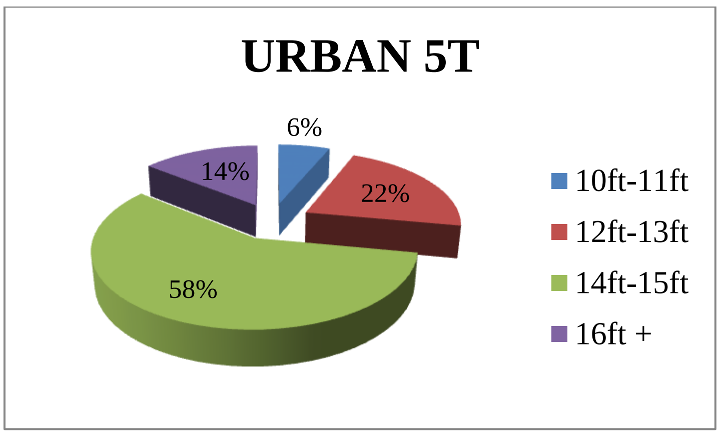


Figure 3-9: Distribution of urban 5T TWLTL widths from Phase A of the study

Another design aspect of the scenarios that needed to be taken into consideration was the development of the gaps for the 3T and 5T sections. The goal here was to try and emulate the traffic as realistically as possible to get the drivers to perform a left turn maneuver as they would in the real world. To help produce randomization each participant was exposed to two sets of traffic intervals at each left turn. The first interval was composed of several small gaps under 2 s that were unlikely to be accepted by the participants. The second set consisted of 50 gaps that ranged from 3.5-8.0 s. The gaps in this set were arranged in a pseudo-random order. The specific values can be seen in Appendix A. The gaps were implemented into the scenarios through the use of various triggers and TCL coding. Once each scenario was laid out the final step included adding a data collection trigger that would continuously collect lane position, speed, heading, vehicle position, and gap acceptance.

One consideration throughout the design process was how to minimize the effect of simulator sickness. The main cause of simulator sickness in the scenarios was due to the abundance of left turns. To ensure that drivers initialted left turns from TWLTLs at similar locations the participant was guided by a yellow "follow car" (Figure 3-10. The follow car would guide the driver to enter a driveway or development which would trigger the warp command. This would cause the screens of the simulator to turn black for a few seconds. When the screens returned the subject vehicle would be placed at the exit of the development where they needed to make the left turn. This helped to eliminate many extra left turns in the scenarios. Due to the lengthy time period required for testing, bias measures were also taken into account. To reduce the effects of driver fatigue and driver recognition the order that each participant drove the scenarios was randomized. This allowed for each scenario to be driven first, second and last an equal number of times.

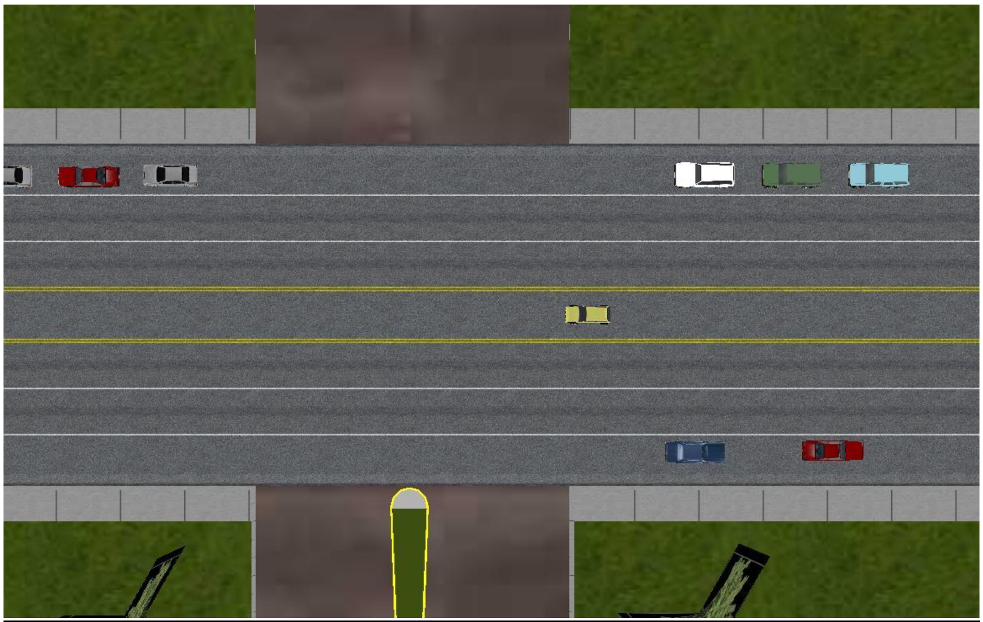


Figure 3-10: Yellow follow car in 5T section

3.4.3 Experimental Procedures

All tests for the experiment were conducted by a proctor that read from a set script which can be found in Appendix C. The script was used to maintain uniformity and provide a controlled experiment as there were four people who conducted the experiment for different participants. Before participating in the study, all subjects were required to read and sign a consent form. Then they were asked a series of demographic questions pertaining to their age, gender, and driver's license ownership which was recorded on the participant data sheet which can be found in Appendix D. Next, the participant's blood pressure was measured. Five readings were recorded during a time span of five minutes.

Afterwards, the participants were asked to sit in the car as they were taught about the various operations of the vehicle. Before driving the three test scenarios each participant drove a series of five adaptation scenarios to familiarize them with the driving simulator and test if they get motion sickness. A detailed explanation of the adaptation scenarios can be found in the previous section under Project Details and Layout. Throughout the adaptation scenarios participants were given breaks if they seemed necessary. At the end of each driving session, adaptation and experimental, participants were asked a series of motion sickness questions that were rated from 0-10, with 10 being severe. Examples of these questions include, dizzy, light headed, nauseous, and sweaty. The remaining questions can be found in the data sheets in Appendix D and Appendix F.

After the training sessions participants were instructed to drive as he/she would in their own vehicles as they drove the test scenarios. These consisted of three scenarios that lasted approximately 15 minutes each to complete. All three scenarios tested lane position, gap acceptance and maneuverability into TWLTLs. Scenario differences lied in the roadway geometry. To be specific, scenario 1 tested lane position on 12 ft. lanes and no paved shoulder for the rural section and gap acceptance and maneuverability on a 12 ft. TWLTL width for the two 3T turns and a 16 ft. TWLTL width for the two 5T turns. Scenario 2 had a 12 ft. lane and 2 ft. paved shoulder for the rural section, 16 ft. TWLTL width for the 3Ts and a 14 ft. TWLTL lane for the 5Ts. Lastly, scenario 3 had 10 ft. lanes with a 2 ft. shoulder for the rural section and 16 ft. TWLTL width for the 3Ts and 12 ft. TWLTL width for the 5Ts. In between each of the test scenarios the participants took a break and were asked to complete a safety survey. The survey had various images of different roadways where each participant was asked to rate the scenario in each picture based on their perceived safety. At the very end of the testing session five readings of the participant's blood pressure were taken for a span of five minutes. The blood pressure measurements and the safety survey helped to distract participants from the actual variables that were tested in the study.

3.5 Procedures for Data Analysis

3.5.1 Rural Driving Section

Continuous data collected from the authoring computer included speed, lane position, vehicle heading, and vehicle position among others. For the rural section the primary variable was the vehicle lane position. Based on the vehicle lane position each participant's percent time out of lane per curve and total number of left or right edge touches was calculated. Lane position values were defined by the driving simulator as the distance between the center of the car to the center of the traveling lane (See Figure 3-11). The value was negative if the center of the car moved to the left of the lane and positive if the car moved to the right. Given continuous lane position data for this roadway segment percent time out of lane and the number of out of lane encroachments were calculated for each participant. The vehicle was considered to be out of lane if any portion of the vehicle touched or crossed the white line on the right side of the lane or the double yellow line to the left of the lane. An example of this can be seen in Figure 3-12.

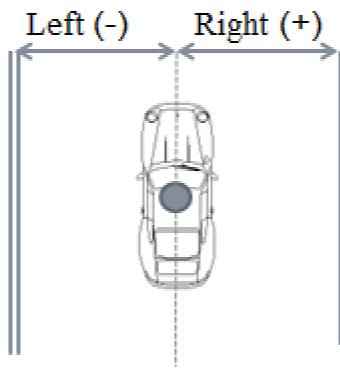


Figure 3-11: Lane position orientation

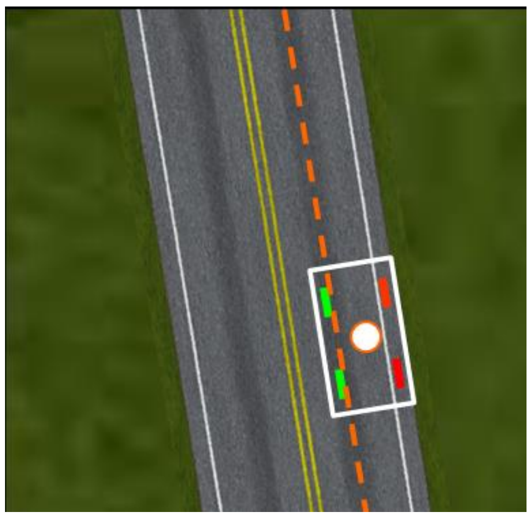


Figure 3-12: Out of lane encroachment

The simulated vehicle was a 5.11 ft. wide Ford Focus and the lane was 12 ft. for Scenario 1 and 2, participants had to have lane position values that were either exceeding 1.0488 or below -1.0488 to be considered out of the lane. Scenario 3 had a 10 ft. lane and participants were considered out of the lane if the lane position values were greater than 0.744 or less than -0.744. Each curve and straight section was designated by the starting and ending X and Y coordinates (Figure 3-13). The specific coordinates chosen for each segment can be found in Appendix B. Based on these boundaries the number of right and left edge touches and percent time out of lane was calculated for each section.

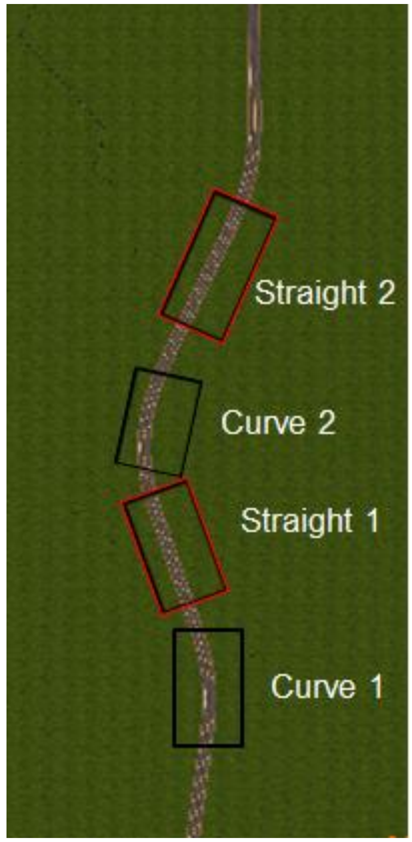


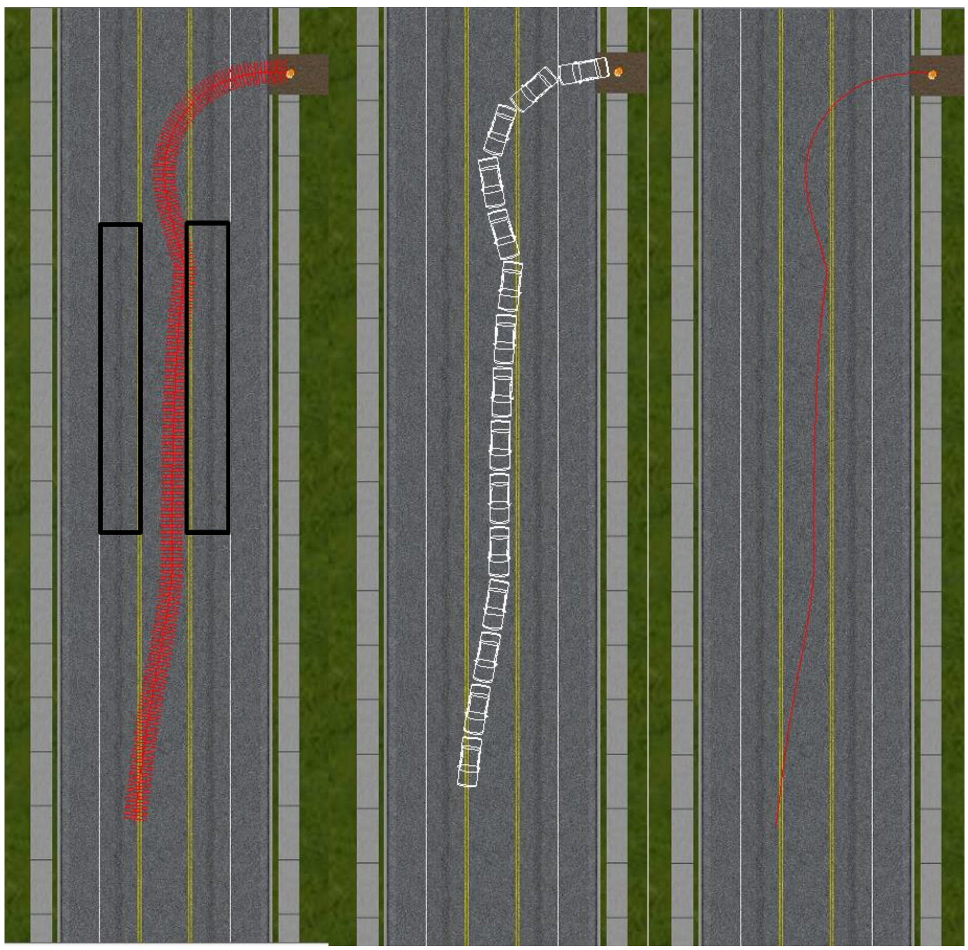
Figure 3-13: Curve and straight section boundaries

3.5.2 Gap Acceptance Section

For each scenario the mean and standard deviation of the accepted gap were computed separately for 3T and 5T turns. A randomized block design was implemented to determine if there was statistical significance between the average gaps per scenario. In this design, the different lane widths in each scenario were the treatment, and the block factor was the participant. Since many participants waited the longest during their first 3T in their first scenario, another evaluation was conducted after removing the first 3T left turn for each participant. Further, the first turn for every participant in each scenario had to be removed to reduce repeated measures so that each participant contributed an equal amount of data points per scenario. A randomized block design was also used for the 5T gap data to see if lane width had an effect on gap acceptance.

3.5.3 TWLTL Section

A secondary method, used to analyze effects of the TWLTL operational performance, involved the creation of vehicle trajectories from second-by-second vehicle position data. From these trajectories, relationships between the TWLTL width and the participants' maneuverability became more apparent. For this study, trajectories from all three scenarios for the second 3T were created for a sample of 30 participants. The trajectories were drawn by applying the vehicle's X and Y coordinates over the roadway geometry in AutoCAD. Three different layers (hash marks indicating the width of the car, a car, and a single vehicle center line) were used to draw the trajectories as seen in image A, B and C of Figure 3-14. For the scope of this study, the numbers of encroachments for the 30 participants in each scenario were analyzed. Boxes were identified to the left and right of the TWLTL in the area that the vehicle would likely occupy as shown in Figure 3-14 A. Each of the one foot interval hash marks (each 1 car width wide) shown in Figure 3-14 A was checked to see if it crossed over into the boxed area. The subject was considered out of the lane if the line crossed the black boundary that is drawn in image A of Figure 3-14. In this case, the vehicle went out of lane on the opposite side from the boxed area. This is one of the few occurrences of lane encroachment for the TWLTL maneuvers.



A B C

Figure 3-14: Vehicle trajectory for 3T section

4 RESULTS

The results are provided in three sections. First, descriptive data representing the percent time out of lane and number of out of lane encroachments per scenario for the rural section is presented. In the second section, comparisons between the six TWLTL widths were statistically examined to determine if there was a significant effect upon gap acceptance. Descriptive statistics were also performed to determine a relationship between age and gender on gap acceptance. Lastly, a sample of 3T trajectories was examined to determine the effect different TWLTL widths have on driver maneuverability.

All inferential tests were completed as a random block design with an alpha of .05. To reduce the variability of repeated measures, the participant was the block and the scenarios were the treatment. Based on the design, multiple comparison ANOVAs were produced. Additional simple effect tests were used if significant interactions were found.

4.1 Rural Curvy Section

4.1.1 Percent Time Out of Lane

The first step taken to analyze the curvy rural section for each scenario involved calculating the percent time out of lane for each participant in each scenario. For Scenario 1, a total of 5 participants went out of lane on the 12 ft. roadway with no paved shoulder. Scenario 2 had a 12 ft. roadway and a 2 ft. shoulder and had a total of 7 participants drive out of the lane. Lastly, Scenario 3 had a 10 ft. roadway and a 2 ft. shoulder and had a high of 14 participants drive out of the lane. Specific percent time out of lane values for each scenario can be seen in Tables 4-1 through 4-3. From the tables, a pattern emerges showing that many of the participants that went out of the lane in Scenario 1 also proceeded to go out of the lane in the following scenarios. After looking at age, gender, and post test questions regarding crashes and speeding tickets, no significant correlation between the participant's characteristics with their ability to stay within the lane. Results from the analysis show very little difference between Scenario 1 and 2. The reduced lane width of 10 ft. in Scenario 3 proved to be more challenging as more participants failed to stay within the lane boundaries. While encroachments for scenario 1 with no shoulder obviously left the paved surface, none of the encroachments for scenarios 2 or 3 left the paved 2 ft. shoulder area during the experiment.

Table 4-1: 12 ft. lane no shoulder- Percent time out of lane data

SCENARIO 1												
C= Curve				**Radius (m)**		418	378	416.8	352.7	375.9	604.3	362.3
S=Straight				**Radius (ft.)**		1371.4	1240.2	1367.5	1157.2	1233.3	1982.6	1188.6
Length (ft.)	1622.0	348.6	658.0	422.2	448.8	415.8	657.6	511.0	466.7	642.7	448.8	628.2
Participant #	**S1**	**S3**	**S4**	**S5**	**S6**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
11	-	-	-	-	-	-	-	-	**11.2%**	-	-	-
22	-	-	-	-	-	-	-	-	-	**3.0%**	-	-
44	-	-	-	-	-	**12.3%**	-	-	-	-	**44.6%**	-
48	-	-	-	-	-	-	-	-	-	-	**23.8%**	-
61	-	-	-	-	-	-	-	-	-	-	**9.5%**	-

Table 4-2: 12 ft. lane 2 ft. shoulder- Percent time out of lane data

SCENARIO 2												
C= Curve				**Radius (m)**		418	378	416.8	352.7	375.9	604.3	362.3
S=Straight				**Radius (ft.)**		1371.4	1240.2	1367.5	1157.2	1233.3	1982.6	1188.6
Length (ft.)	1622.0	348.6	658.0	422.2	448.8	415.8	657.6	511.0	466.7	642.7	448.8	628.2
Participant #	**S1**	**S3**	**S4**	**S5**	**S6**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**
11	-	-	-	-	-	-	-	-	-	-	**28.3%**	-
22	**6.4%**	-	-	-	-	-	**39.4%**	-	-	-	-	-
32	-	-	-	-	-	-	**17.1%**	-	-	-	-	-
36	-	-	-	-	-	**36.1%**	-	-	-	-	-	-
44	-	-	-	-	-	**0.3%**	-	-	**22.5%**	-	**73.2%**	-
46	-	-	-	-	-	-	-	**1.5%**	-	-	-	-
48	-	-	-	-	-	-	-	-	-	**16.9%**	**21.7%**	-

Table 4-3: 10 ft. lane 2ft. shoulder- Percent time out of lane data

SCENARIO 3										
C=Curve			**Radius (m)**		654	370	296	344	451.6	1665
S=Straight			**Radius (ft.)**		2145.7	1213.9	971.1	1128.6	1481.6	5462.6
Length (ft.)	485.8	545.7	279.7	811.1	675.6	740.1	1033.2	926.6	588.8	661.7
Participant #	**S13**	**S12**	**S10**	**S8**	**C13**	**C12**	**C11**	**C10**	**C9**	**C8**
5	-	-	-	-	-	-	**12.3%**	-	**13.9%**	-
7	-	-	-	-	-	-	-	-	**38.0%**	-
8	-	-	-	-	-	**15.7%**	-	**12.6%**	-	-
11	-	-	-	-	**9.1%**	-	-	**8.6%**	-	-
20	-	-	-	-	**14.3%**	-	-	-	-	-
22	-	-	-	-	-	-	-	-	**29.0%**	-
31	-	-	-	-	-	-	-	**4.07%**	-	-
36	-	-	-	-	-	**22.7%**	-	**21.8%**	-	**13.9%**
42	-	**15.8%**	**49.5%**	-	-	**6.5%**	-	-	-	-
44	-	-	-	-	-	**53.1%**	**13.2%**	**29.1%**	**26.7%**	-
48	-	-	-	-	-	**1.9%**	**80.0%**	-	-	-
50	-	-	-	-	-	-	-	**6.3%**	-	-
61	-	-	-	-	-	-	**16.1%**	**11.9%**	-	-
64	-	-	-	-	**15.5%**	-	-	-	-	-

The tables also express that those who did go out of the lane typically did so on curvy sections of the roadway. Only a single driver (participant 42) out of 60 participants left the 10 ft section of scenario 3. It appears that this driver was favoring the shoulder side of the lane. A further evaluation was conducted by calculating each participant's cumulative time out of lane for all curves and creating a histogram for each scenario (Figures 4-1 through 4-3). The 85th, 90th, and 95th percentile values for time out of lane for Scenario 1, 2 and 3 was determined and are shown in Table 4-4. The 85th percentile values were 0%, 0% and 2.59% respectively. This further indicates no difference between Scenario 1 and 2 as 85% of the participants did not drive out of the lane on either scenario. However, the 10ft lane with a 2ft. shoulder in Scenario 3 had a significant impact on lane position as 85 percent of people drove out of the lane 2.59% of the time.

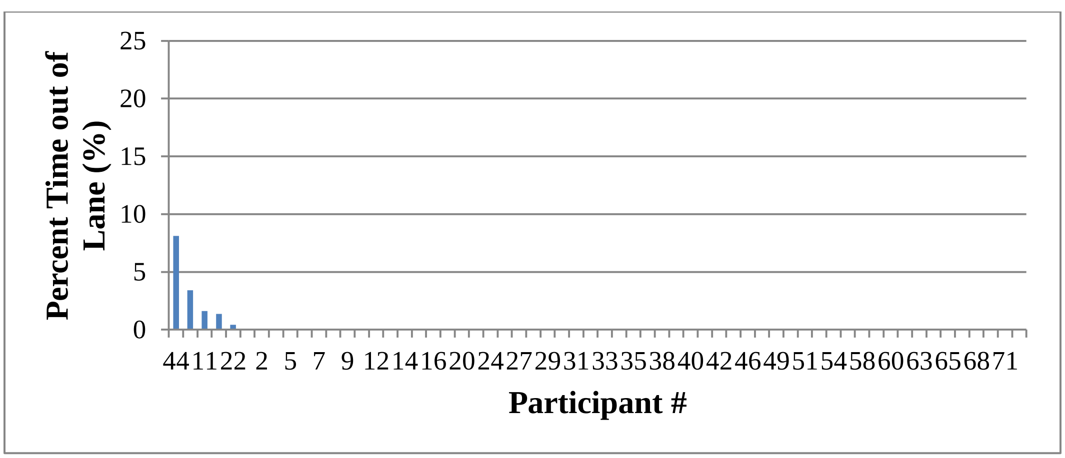


Figure 4-1: Scenario 1- Percent time out of lane in curves

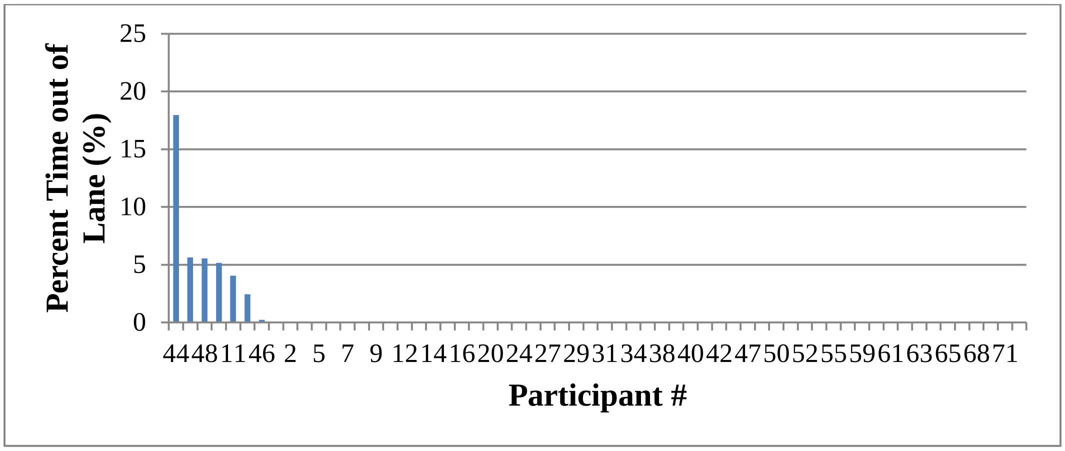


Figure 4-2: Scenario 2- Percent time out of lane in curves

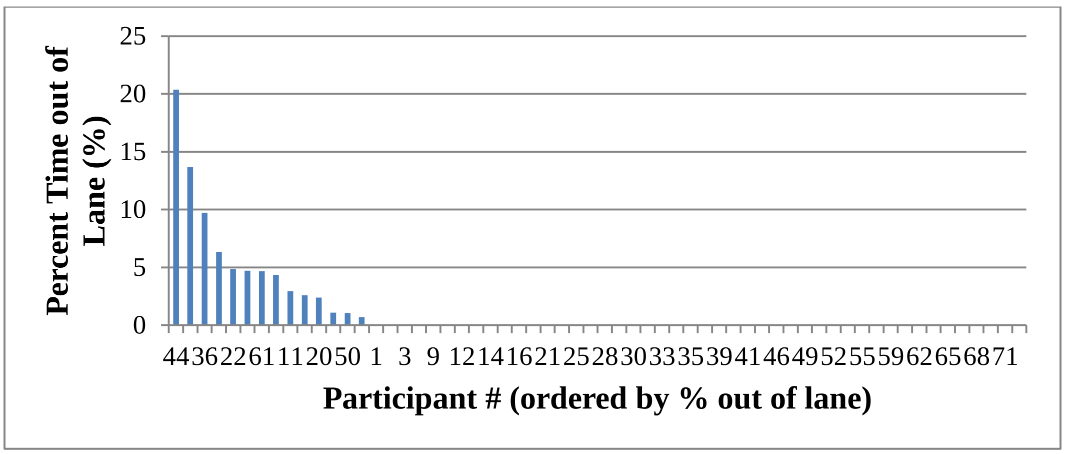


Figure 4-3: Scenario 3- Percent time out of lane in curves

Table 4-4: Total Percent Time out of lane for Curves by percentile

Percentile	Scenario 1	Scenario 2	Scenario 3
85th	0.00 %	0.00 %	2.59 %
90th	0.00 %	0.22 %	4.66 %
95th	1.36 %	5.15 %	6.34 %

4.1.2 Number of Out of Lane Encroachments

Effects from the lane/shoulder width combinations were further analyzed by observing the total number of left and right encroachments for each scenario. Right hand encroachments were defined by the participant crossing the white line on the right side of the lane. Left hand encroachments were cases when the participant moved towards the left of the lane touching or crossing the center line of the roadway. A summary of the encroachment data is given in Table 4-5 for Scenarios 1 and 2; and Table 4-7 for Scenario 3. Curve radii tables are repeated in Tables 4-6 (Scenarios 1 and 2) and 4-8 (Scenario 3) for comparison purposes.

For Scenario 1 with a 12 ft. lane width and no shoulder, there were 1 right and 5 left encroachments. Due to the absence of a shoulder, it is evident that the participants gravitated toward the center of the roadway to avoid going off the road. The 12 ft. lane and 2 ft. shoulder roadway in Scenario 2 had a total of 7 left and 6 right hand encroachments. With the nearly equal split of encroachments on left and right, the vehicle tended to remain more centered in the lane, but the deviation increased with the added shoulder width. It is expected from prior literature, that the extra space given by the shoulder creates an illusion for the drivers that the road is safer. From this sense of security, it is possible that the participants felt they had more room for errors and corrections thus causing them to utilize more of the roadway width in which these encroachments occurred. The last combination of 10 ft. lanes and a 2ft. shoulder in Scenario 3 exhibited the highest numbers of encroachments with 14 left and 16 right encroachments. The significant increase in encroachments for this combination indicates that the reduced lane width had an effect upon lane position. While there were encroachments for each scenario, none of the crossings in Scenario 2 and 3 exceeded the boundaries of the shoulder.

Table 4-5: Left and right encroachments for Scenario 1&2

	Scenario 1 12 ft. lane, no shoulder		**Scenario 2 12 ft. lane, 2 ft. shoulder**	
Section Type	**Left**	**Right**	**Left**	**Right**
Straight 1	-	-	-	1
Straight 3	-	-	-	-
Straight 4	-	-	-	-
Straight 5	-	-	-	-
Straight 6	-	-	-	-
Curve 1 (Left)	1	-	2	-
Curve 2 (Right)	-	-	-	4
Curve 3 (Left)	-	-	1	-
Curve 4 (Left)	1	-	1	-
Curve 5 (Right)	-	1	-	1
Curve 6 (Left)	3	-	3	-
Curve 7 (Right)	-	-	-	-
Total	5	1	7	6

Table 4-6: Curve details for Scenario 1&2

	Radii (m)	**Radii (ft.)**
Curve 1	418	1371.4
Curve 2	378	1240.2
Curve 3	416.8	1367.5
Curve 4	352.7	1157.2
Curve 5	375.9	1233.3
Curve 6	604.3	1982.6
Curve 7	362.3	1188.6

Table 4-7: Left and right encroachments for Scenario 3

Scenario 3 10ft lane, 2 ft. shoulder		
Section Type	**Left**	**Right**
Straight 13	-	-
Straight 12	-	1
Straight 10	-	1
Straight 8	-	-
Curve 13 (Right)	-	3
Curve 12 (Left)	5	1
Curve 11 (Right)	-	4
Curve 10 (Left)	8	-
Curve 9 (Right)	0	6
Curve 8 (Left)	1	-
Total	14	16

Table 4-8: Curve details for Scenario 3

	Radii (m)	**Radii (ft.)**
Curve 13	654	2145.7
Curve 12	370	1213.9
Curve 11	296	971.1
Curve 10	344	1128.6
Curve 9	451.6	1481.6
Curve 8	1665	5462.6

Effects from the 10ft. roadway were further identified by creating histograms to determine the 85^{th}, 90^{th} and 95^{th} percentile for each scenario. The 85^{th} percentile fell at 2 encroachments for Scenario 3 and 0 encroachments for Scenario 1 and 2 (Table 4-9). Encroachment histograms for the 3 scenarios are given in Figures 4-4, 4-5, and 4-6. Based on the relationship between lane position and presence of curves for the 10 ft. roadway, as well as results for percent time spent out of lane and number of encroachments, it can be suggested that curve widening be applied on 10 ft. roadways.

Table 4-9: Total number of encroachments

Percentile	Scenario 1	Scenario 2	Scenario 3
85th	0	0	2
90th	0	1	2
95th	1	2	2

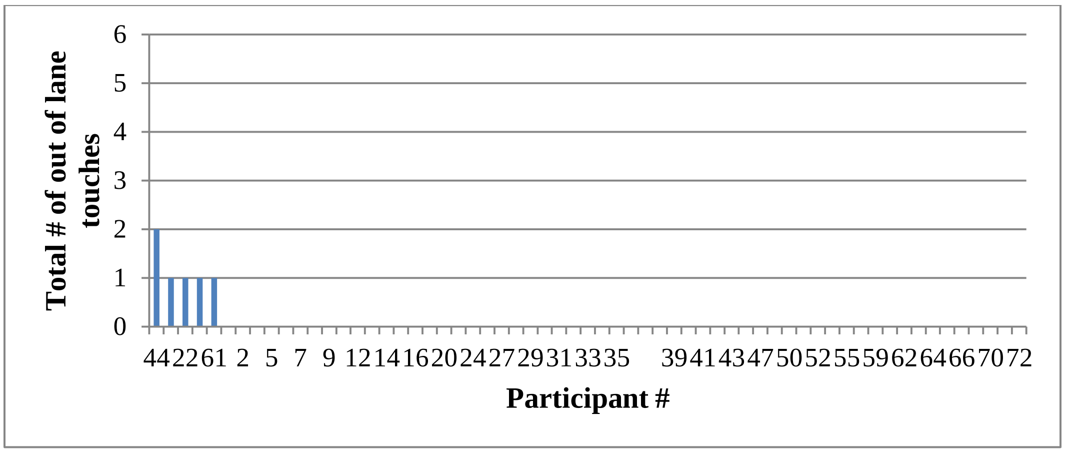


Figure 4-4: Scenario 1 (12 ft.-0 ft.) total encroachments

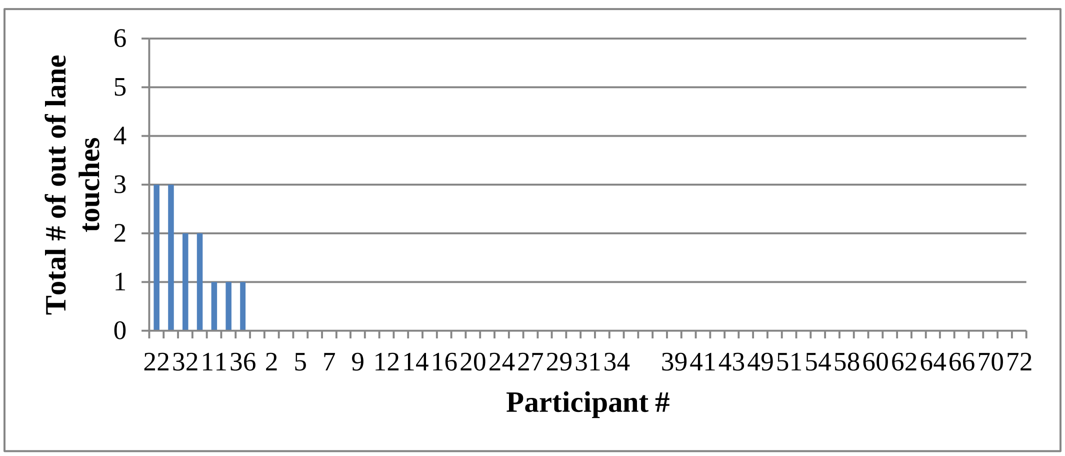


Figure 4-5: Scenario 2 (12 ft.-2 ft.) total encroachments

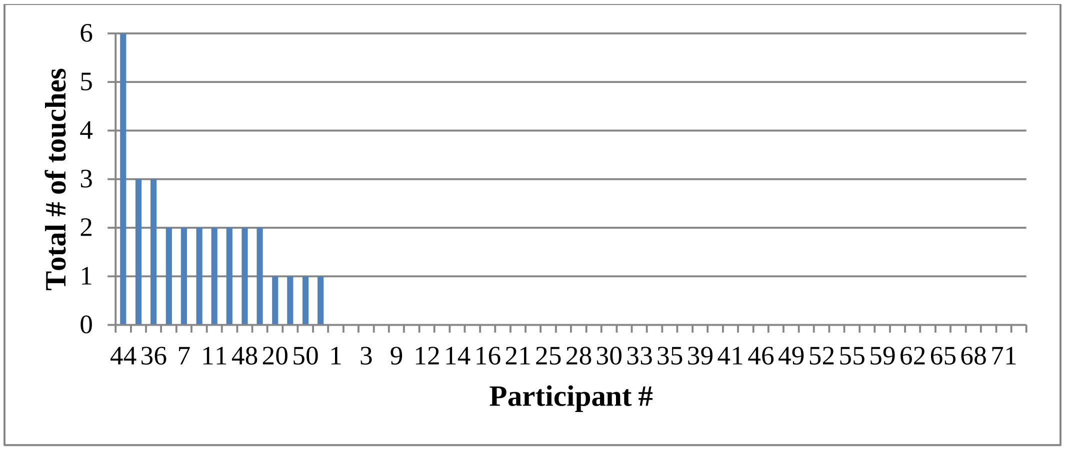


Figure 4-6: Scenario 3 (10 ft.-2 ft.) total encroachments

Lane position was further investigated by comparing the average lane position and standard deviation for each roadway combination. As seen in Table 4-10 the average lane position for Scenario 1 and 2 were towards the left with values of -0.212 ft. and -0.100 ft. respectively. Scenario 3 had an average lane position towards the right of the lane at 0.149 ft. From these values it is evident that the roadway without a shoulder caused the participants to drive more towards the left of the lane to avoid driving off the road. The standard deviation values for each scenario also show that more variation was found for the two 12 ft. roadways. The standard deviation reduced for the narrower lane width of 10 ft. as the participants focused on maintaining their position within the lane. These results further substantiate the relationship found in Ben-Bassat and Shinar's (2011) study indicating that the standard deviation of lane position increases as the roadway width increases. Statistical analysis showed that the roadway combination did have an effect upon the mean lane position. Results from the test are expressed in Table 4-11.

Table 4-10: Lane position statistics

	Scenario 1 (12 ft.-0 ft.)	Scenario 2 (12 ft.-2 ft.)	Scenario 3 (10 ft.-2 ft.)
Avg. Lane Position (ft.)	-0.212	-0.100	0.149
Avg. Std. Deviation (ft.)	0.459	0.461	0.369

Table 4-11: Ordered differences report

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
S3	S1	0.1098845	0.0115862	0.0823827	0.137386	<.0001*
S3	S2	0.0759006	0.0115862	0.0483988	0.103402	<.0001*
S2	S1	0.0339839	0.0115862	0.0064821	0.061485	0.0112*

Observations were also made regarding the relationship between the number of encroachments and curve radii. All of the curve radii in the three scenarios were split into three categories of small, medium and large. The small curves fell in the range of 900-1230 ft. Curves within the range of 1231-1500 ft. were recognized as medium and large curves were between 1501-5500 ft. Based on these ranges and the radii of the curves given in the scenarios, more encroachments were experienced on the smaller radii curves. Curves to the left were also more involved than curves to the right.

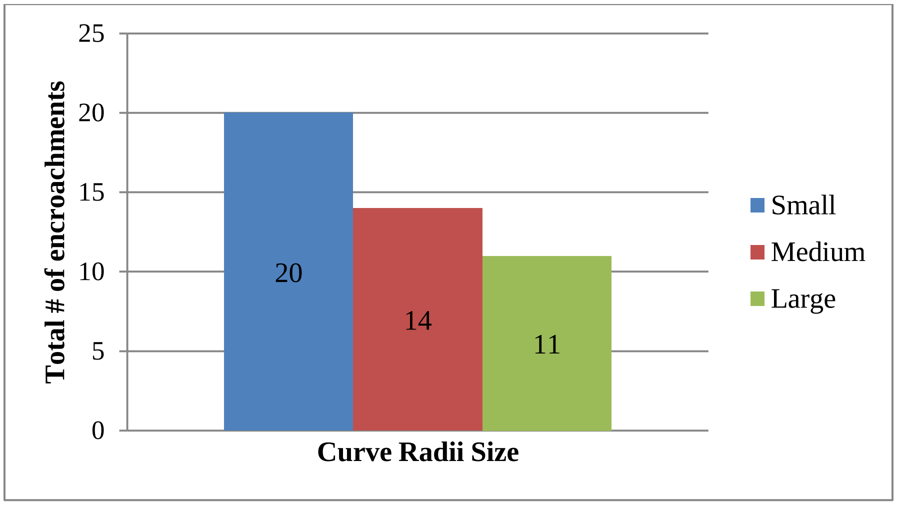


Figure 4-7: Effects of roadway geometry on vehicle encroachments

4.2 Left Turns into TWLTL

In each scenario there were two sections that had a three lane roadway with a center lane (3T) and two sections that had a five lane roadway with a center lane (5T). During these sections, participants performed left turns from a driveway into a two-way left turn lane. From these various left turns, analyses were performed to determine if the width of the TWLTL had any effect upon gap acceptance, delay, and operational maneuverability.   Each of these measures will be presented in following sections, along with additional analyses for gender and fatigue bias.

4.2.1 Gap Acceptance for 3T Scenario

As participants entered the continuous town section they completed the left turns in the order of the first 3T followed by both 5T sections and ended the scenario with the last 3T. Each participant had a total of two 3T gaps recorded for each scenario.

The first analysis, to determine if the TWLTL width affected gap acceptance for the 3T sections, was conducted by comparing the mean gap for each scenario in a completely random block design. The data set used for this test included both turns for each participant for all three scenarios. The mean gap values were 5.4 s for Scenario 1, 5.3 s for Scenario 2 and 5.1 s for Scenario 3 Figure 4-8 shows a plot of the gap data and identifies the means for each scenario. Results from the ANOVA found no significance between the means, thus indicating that the TWLTL width had no effect upon gap acceptance (p= .1137) (Figure 4-9). Analysis of the performance order, for the first and second attempts at the 3T turn, indicate that the order was statistically significant (p= <.0001). The researchers hypothesized that participants generally took larger gaps on the first turn as they were not yet familiar with making a left turn in this type of setting in the simulator. To remove any effect caused by the first turn data an additional ANOVA was performed on a data set containing only the second turn gaps for each scenario. The the gap data and average gaps for the second 3T left turn are shown in Figure 4-1. Despite the removal of the first turn, the standard deviation values varied little and the mode remained 5 or 6 s as compared to the data set containing all turns. Results from this ANOVA shown in Table 4-12 also expressed that the TWLTL width had no effect upon gap acceptance (p=.1182).

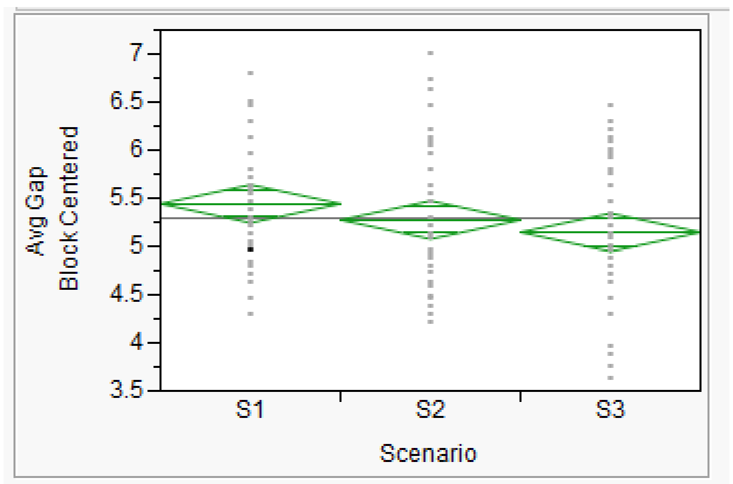


Figure 4-8: All 3T turns

Table 4-12: Analysis of Variance for all 3T turns

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Scenario	2	2.64718	1.32359	2.2149	0.1137
Participant	59	181.3	3.07288	5.1421	<.0001*
Error	118	70.51631	0.5976	-	-
C. Total	179	254.4635	-	-	-

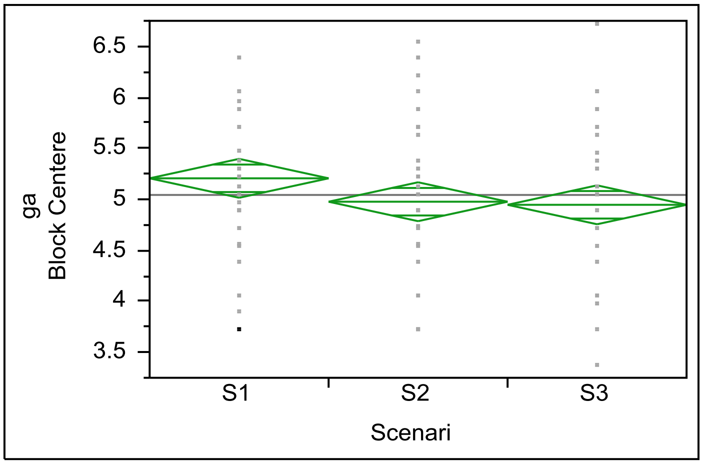


Figure 4-9: Second 3T turn

Table 4-13: Analysis of Variance for second 3T turn

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Scenario	2	2.4201	1.21007	2.1742	0.1182
Participant	59	227.885	3.86247	6.9399	<.0001*
Error	118	65.6739	0.55656	-	-
C. Total	179	295.979	-	-	-

To further investigate the effect produced based on the order of the turn, additional tests were performed to compare the mean values of the first 3T turn to the second 3T turn for each scenario. Mean gap values for the first turn were 5.7 s for Scenario 1, 5.6 s for Scenario 2 and 5.4 s for Scenario 3. The mean gap values for the second turn were 5.2 s, 5.0 s and 4.9 s respectively. From these values it is clear that on average participants took larger gaps on their first turn than the second turn for each scenario. As stated previously, it was assumed that after performing the first left turn maneuver the driver became more accustomed to the simulator; thus, causing them to accept a smaller gap for the second 3T left turn. Several matched pairs comparisons revealed that the mean values between the first and second turn for each scenario were statistically significant. Statistical summary statistics for all of the 3T gap data are shown in Tables 4-14, 4-15, and 4-16.

Table 4-14: Gap Data for All 3T turns

Statistics	Scenario 1 (12 ft.)	Scenario 2 (16 ft.)	Scenario 3 (14 ft.)
Avg. Gap (s)	5.4	5.3	5.1
Std. Deviation	1.3	1.3	1.3
Mode	6.0	6.0	6.0
Median	6.0	5.0	5.0

Table 4-15: Gap Data for First 3T turn

Statistics	Scenario 1 (12 ft.)	Scenario 2 (16 ft.)	Scenario 3 (14 ft.)
Avg. Gap (s)	5.7	5.6	5.4
Std. Deviation	1.2	1.4	1.3
Mode	7.0	6.0	6.0
Median	6.0	6.0	6.0

Table 4-16: Gap Data for Second 3T turn

Statistics	Scenario 1 (12 ft.)	Scenario 2 (16 ft.)	Scenario 3 (14 ft.)
Avg. Gap (s)	5.2	5.0	4.9
Std. Deviation	1.4	1.2	1.3
Mode	6.0	6.0	5.0
Median	5.0	5.0	5.0

4.2.2 Delay Experienced into 3T TWLTL

Observations were also made based on the delay participants experienced. For each scenario there was very little difference in mean delay for all turns. When broken down into turn order Table 4-17 shows that on average the participants waited longer on their first 3T turn than their second turn. Figure 4-11 and 4-12 show that the interval range was 0-39 for the first turn and 0-14 for the second turn. The histograms also show that for the second turn more people accepted gaps within the first four intervals.

Table 4-17: Average Delay (s)

	Scenario 1 (12 ft.)	Scenario 2 (16 ft.)	Scenario 3 (14 ft.)
All turns	21.1	21.2	20.5
First turn	23.1	25.2	23.8
Second turn	19.2	17.1	17.1

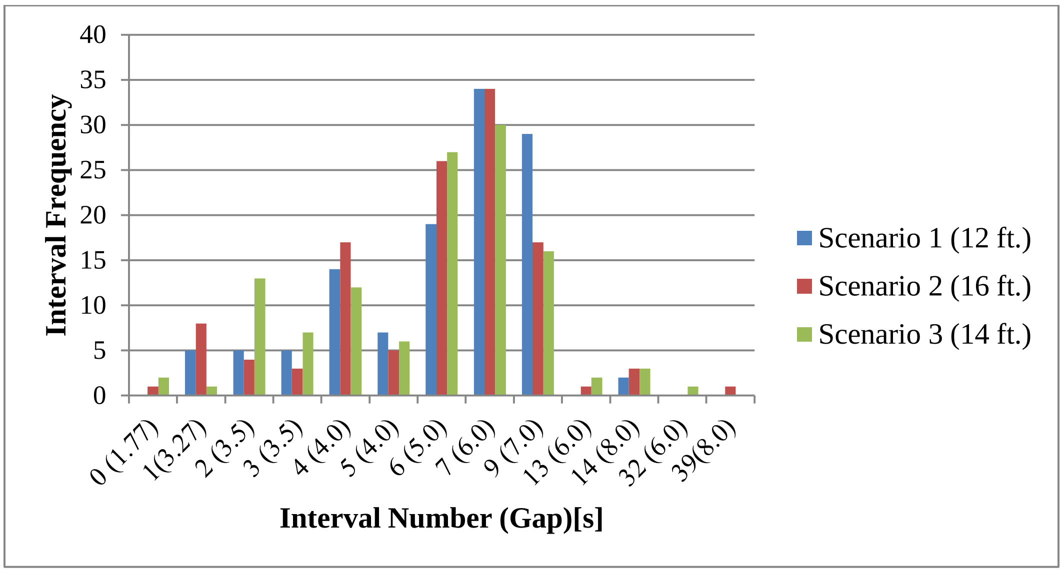


Figure 4-10: Gap interval frequency for All 3T turns

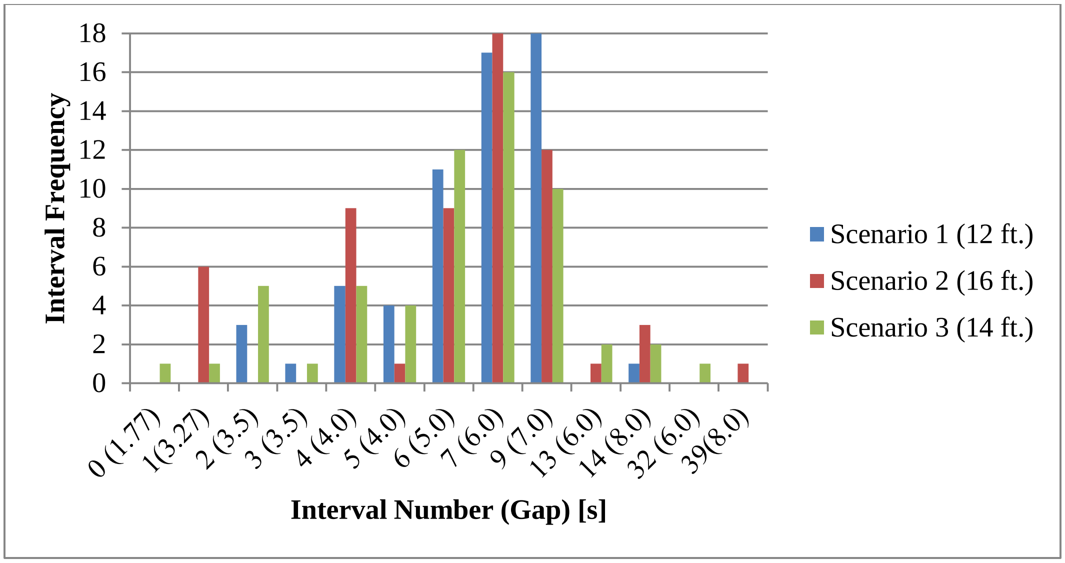


Figure 4-11: Gap interval frequency for First 3T turn

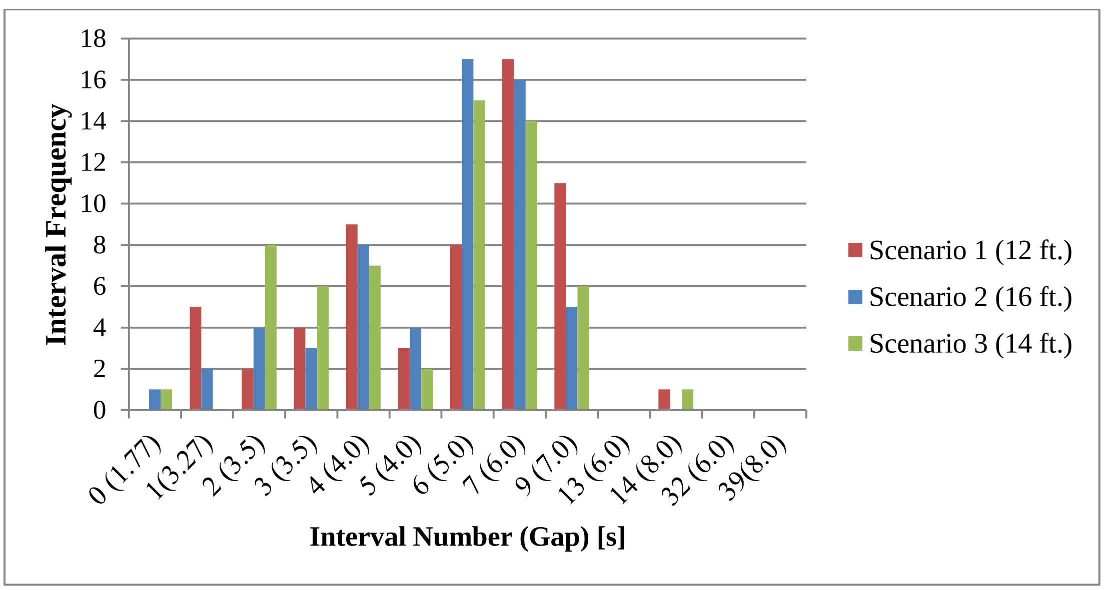


Figure 4-12: Gap interval frequency for second 3T turn

Table 4-18: Cumulative delay per traffic interval for 3T turns

Interval	Delay (s)	Gap (s)
1	1.77	3.27
2	3.27	3.5
3	6.77	3.5
4	10.27	4
5	14.27	4
6	18.27	5
7	23.27	6
9	33.77	7
13	52.77	6
14	58.77	8
32	142.27	6
39	177.77	8

4.2.3 Effect of Scenario Order

The fact that each scenario had identical layouts enabled researchers to conduct a final test to evaluate the effects of driver recognition and fatigue. In an attempt to reduce this effect, the scenario order was evenly and randomly assigned so that an equal number of participants would begin and end with Scenario 1 and so forth for the other scenarios. To test this, the final analysis for the 3T sections compared the mean gap values based on the first, second and third scenario driven. For this test the scenario identifiers were removed as the interest was solely focused on the order that the participants drove the scenarios (first, second, or third). As shown in Table 4-19 the average gap was 5.88 s for the first scenario, 5.08 s for the second and 4.90 s for the last one. The ANOVA from the completely random block design, as shown in Table 4-20, revealed that there was a significant effect produced by the order in which the scenarios were driven($p=<.0001$). Effect tests were then conducted proving that the mean gap of the first scenario driven was higher and statistically significant between the second ($p=<.0001$) and third scenario ($p=<.0001$). However, there was no significance in difference between the drivers performance on the second and third scenarios. The results are expressed in Table 4-21 and 4-22.

Table 4-19: Gap Data for Scenario Order

	First	Second	Third
Avg. Gap (s)	5.88	5.08	4.90
Std. Deviation	0.88	1.14	1.29
Median	6	5.07	4.75
Mode	6	6	4.5

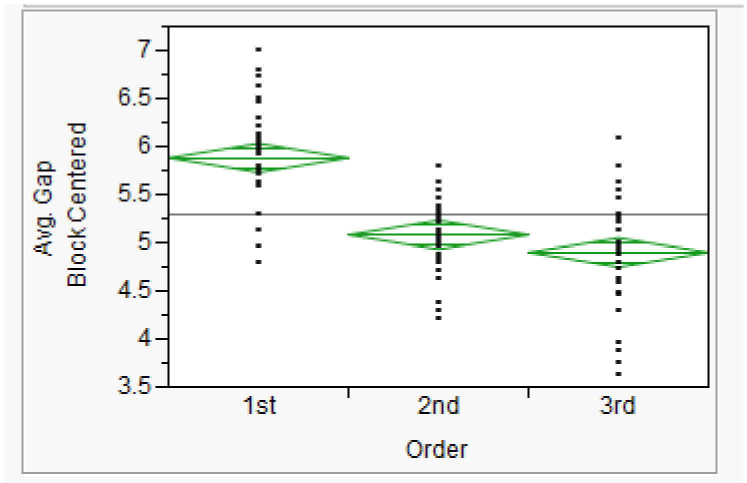


Figure 4-13: Average Gap for Scenario Order

Table 4-20: Analysis of Variance for Scenario Order

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Order	2	32.6932	16.3466	47.6622	<.0001*
Participant	59	181.3	3.0729	8.9597	<.0001*
Error	118	40.4702	0.343	-	-
C. Total	179	254.463	-	-	-

Table 4-21: Pairwise Comparisons for Scenario Order

Level	Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value
1st	3rd	0.981333	0.106922	0.72754	1.23513	<.0001*
1st	2nd	0.799	0.106922	0.54520	1.05280	<.0001*
2nd	3rd	0.182333	0.106922	-0.07147	0.43613	0.2075

These findings suggest that the participants were more apprehensive and cautious when driving the first scenario as they were unfamiliar with the layout. Once the participants became accustomed to the layout and the left turn maneuver, they began to accept smaller gaps in the following scenarios. This trend can also be seen by looking at the delay data (Table 4-22). Similar to the average gap data the average delay was highest for the first scenario driven, and decreased for the next two scenarios. The average delay values are 27.77 s, 18.50 s, and 16.62 s respectively. There is a large difference of 9.27 s between the first and second scenario and a minimal difference of 1.88 s between the second and third scenario. These differences indicate a learning curve took place. For the first scenario many participants waited longer as they anticipated the traffic to stop. Once they realized that the traffic was constantly being generated they eventually accepted a gap and crossed into the TWLTL.

By the second and third scenario the participants felt more comfortable with the setting and began to wait less and take shorter gaps. The frequency of intervals taken can be seen in Figure 4-15. This histogram shows the first gaps accepted were more centrally focused around the 7th interval. However, the second and third attempts were much more distributed through the lower intervals (4th, 6th, and 7th). Clearly more people waited less time during the second and third scenario as there are higher values in the lower intervals from 0 to 4.

Table 4-22: Delay data based on scenario order

	First	Second	Third
Avg. Delay (s)	27.77	18.50	16.62
Median	23.27	18.27	18.27
Mode	23.27	18.27	18.27

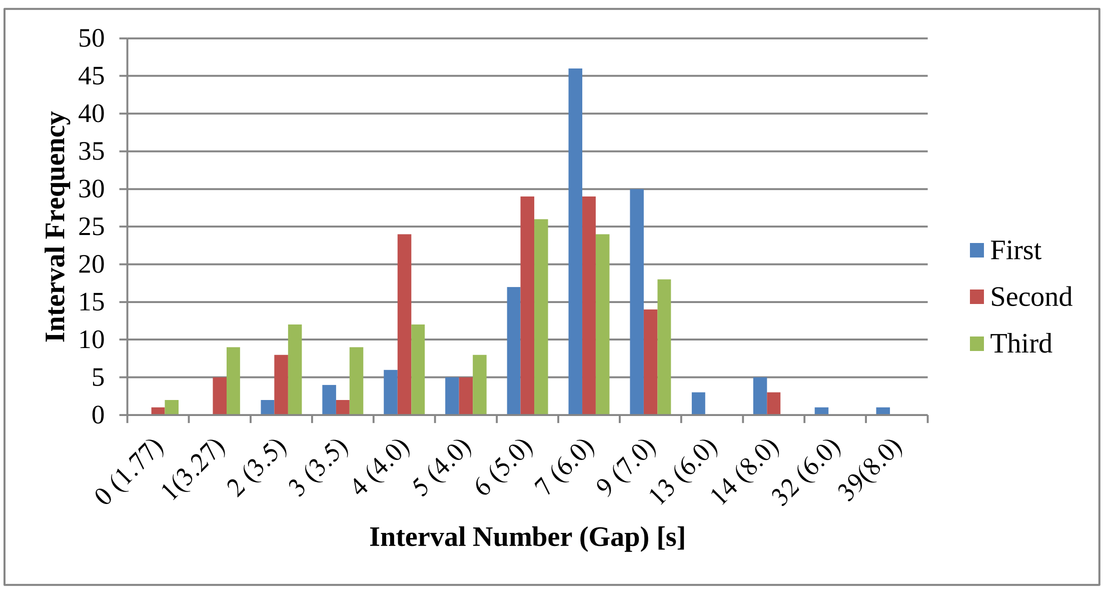


Figure 4-14: Gap interval frequency for scenario order

4.2.4 5T Sections

Between the two 3T sections of each scenario there were two 5T sections. For these sections the center lane was 16 ft. for Scenario 1, 14 ft. for Scenario 2 and 12 ft. for Scenario 3. Summary statistics for the 5T gap data are shown in Table 4-23. The average gaps were 4.6 s, 4.8 s and 4.5 s respectively. Based on these averages no clear trend between the average gap and center lane width is evident. To further assess if the TWLTL width affected gap acceptance a completely random block design was conducted. Results from the ANOVA table show that the TWLTL width in the 5T areas had no effect on gap acceptance (p=.1723). The ANOVA output can be seen in Figure 4-16 and Table 4-23.

Table 4-23: Gap data for all 5T turns

	Scenario 1 (16ft.)	Scenario 2 (14ft.)	Scenario 3 (12ft.)
Avg. Gap (s)	4.6	4.8	4.5
Std. Dev	1.2	1.3	1.1
Median	4.5	4.5	4.3
Mode	5	4.5	4

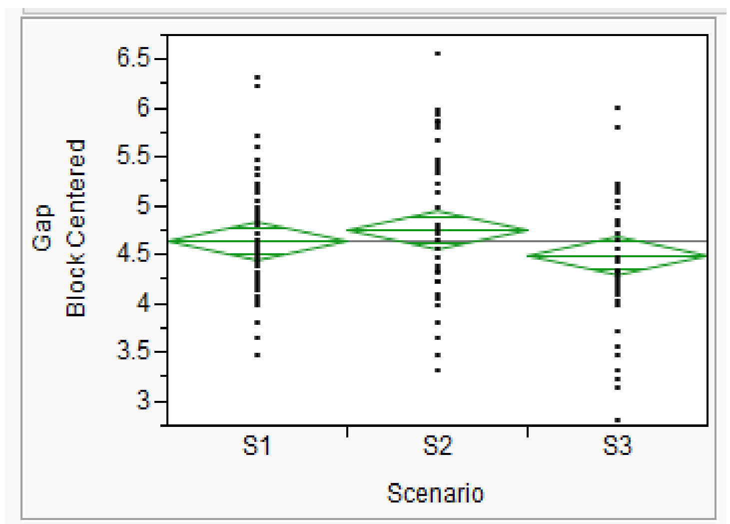


Figure 4-15: Average gap for all 5T turns

Table 4-24: Analysis of Variance for all 5T turns

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Scenario	2	2.0863	1.04313	1.785	0.1723
Participant	59	189.076	3.20468	5.4839	<.0001*
Error	118	68.956	0.58438	-	-
C. Total	179	260.119	-	-	-

Summary statistics for 5T delay data are shown in Table 4-25. The average delay for each scenario was also calculated as 18.32 s for Scenario 1, 20.29 s for Scenario 2 and 17.14 s for Scenario 3. From these results, it appears that participants who waited longer took larger gaps. This correlation can be seen as Scenario 2 had the largest average gap of 4.8 s and the largest average delay of 20.29 s while Scenario 3 had the smallest average gap of 4.5 s and average delay value of 17.14 s. Figure 4-18 shows the distribution of gap intervals that were taken for each scenario. Scenario 3 had the smallest average delay, as many participants accepted gaps in the 2nd or 4th interval. The Scenario 2 average was heavily influenced by the drivers who took the 11th and 16th interval experiencing delays of 39.54 s and a max of 64.5 s as shown in Table 4-26.

Table 4-25: Delay data for all 5T turns

	Scenario 1 (16 ft.)	**Scenario 2 (14 ft.)**	**Scenario 3 (12 ft.)**
Avg. Delay(s)	18.32	20.29	17.14
Median	20.04	14.04	12.04
Mode	20.04	20.04	5.04

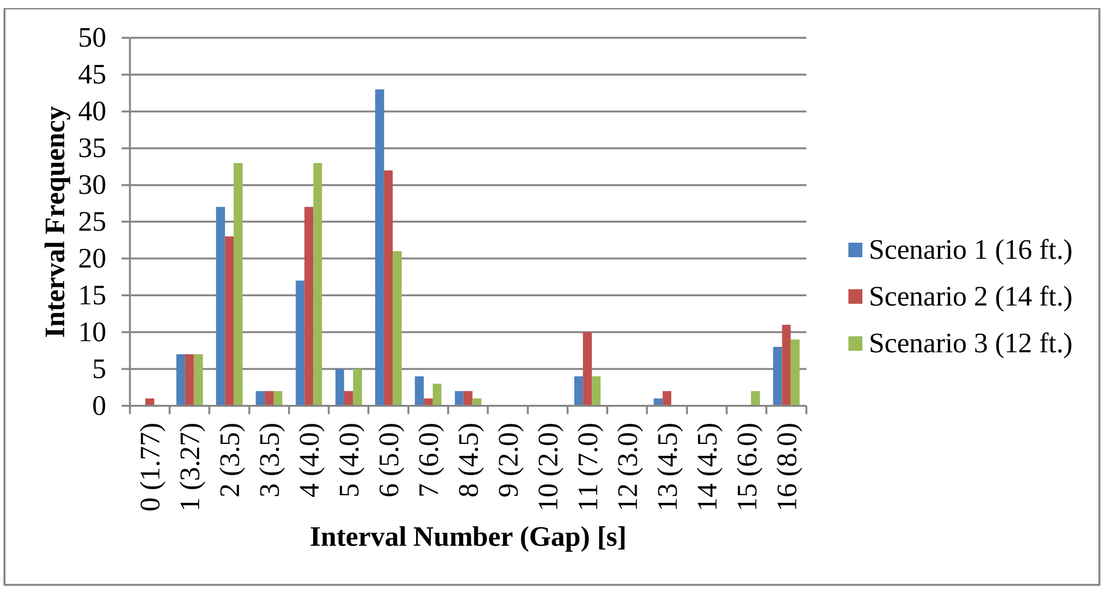


Figure 4-16: Gap interval frequency for 5T turns

Table 4-26: Cumulative delay per traffic interval for 5T turns

Interval	Delay (s)	Gap (s)
0	0	1.77
1	1.77	3.27
2	5.04	3.5
3	8.54	3.5
4	12.04	4
5	16.04	4
6	20.04	5
7	25.04	6
8	31.04	4.5
9	35.54	2
10	37.54	2
11	39.54	7
12	46.54	3
13	49.54	4.5
14	54.04	4.5
15	58.54	6
16	64.54	8

4.2.5 Effects of Age on Gap Acceptance

Throughout the study the participants were defined by two different age groups, younger and older. The younger participants were between the ages of 18 and 35 years old. The older participants were of ages 35 and older. Out of the 60 successful tests, 40 participants were younger and 20 were in the older category. To evaluate how the driver age affected gap acceptance various summary statistic were calculated for the two age groups. As seen in Table 4-27 and 4-28 the younger participants accepted smaller gaps than those in the older age group. The average gap values were all below 5 s for the younger age group and above 5 s for the older age group. The overall average for all turns for each age group was 4.82 s for younger and 5.23 for the older. Results from a comparison test confirmed that these two averages were statistically significant (p=.0002). Similar to the findings of other studies, the older drivers in this simulator driving experiment tended to drive more conservatively.

Table 4-27: Gap data for younger participants

Statistics	Scenario 1	Scenario 2	Scenario 3
Avg. Gap (s)	4.87	4.87	4.72
Std. Dev	1.28	1.43	1.30
Mode	4	4	4
Median	5	4.75	4

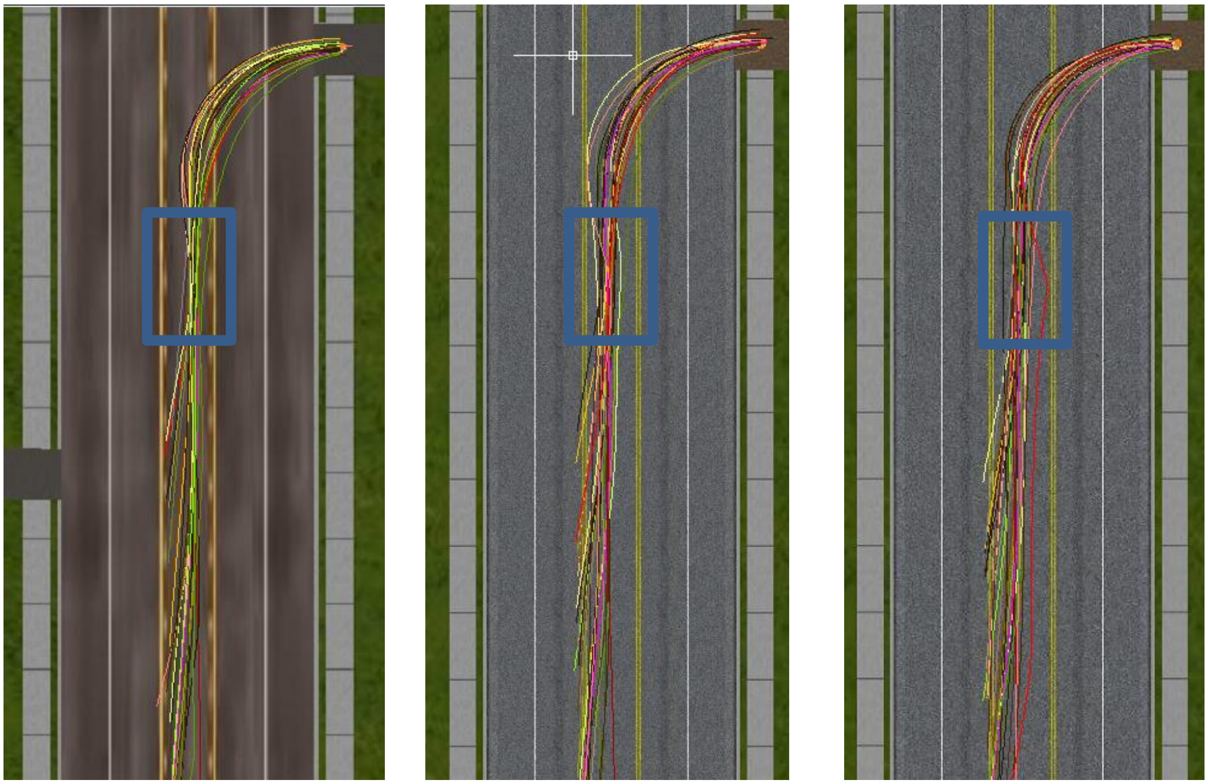
Table 4-28: Gap data for older participants

Statistics	Scenario 1	Scenario 2	Scenario 3
Avg. Gap (s)	5.39	5.30	5.00
Std. Dev	1.39	1.34	1.47
Mode	5	5	6
Median	5	5	5

4.3 Trajectories

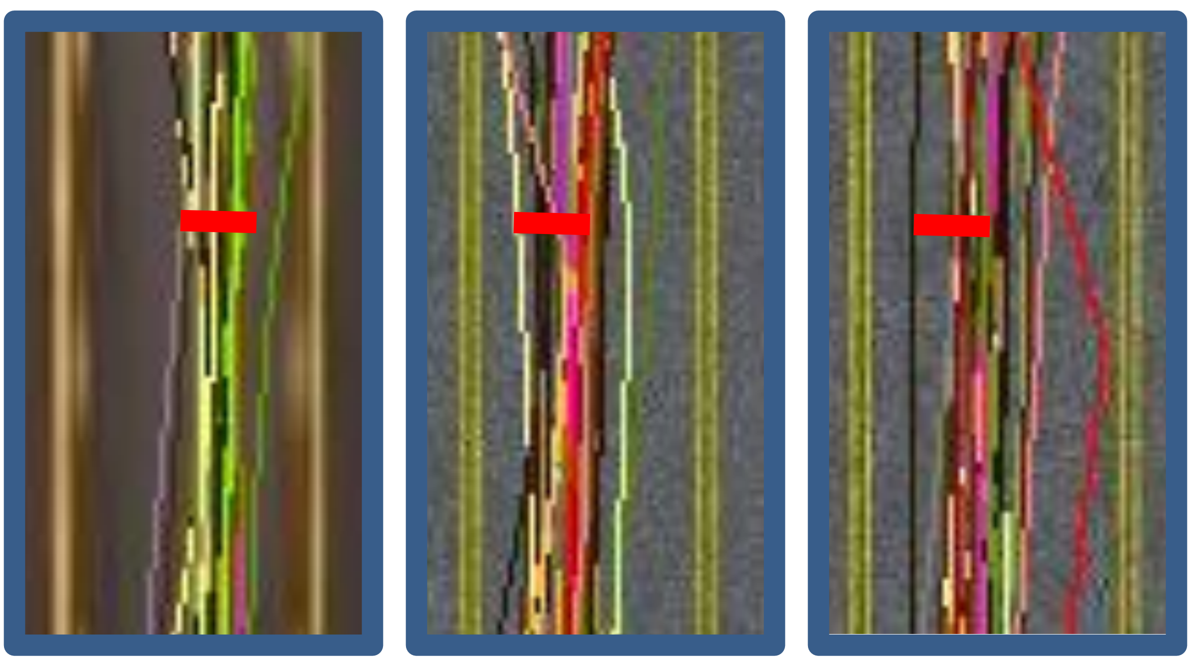
Additional analyses were performed to test how the TWLTL width affected participants' ability to maneuver into and within the TWLTL when they performed their left turn. For the purpose of this study, trajectories were drawn for the second 3T turn for 30 participants shown in Figure 4-18. The trajectories show that the drivers would enter the TWLTL into a common refuge area shown in the blue boxes in Figure 4-18. Some drivers continued down the TWLTL for a distance before moving into the travel lane while other drivers traveled a much shorter distance in the TWLTL.

One measurement of maneuverability was based on the number of encroachments for these 30 participants. Encroachments occurred either before or within the refuge area. Beyond the refuge area, drivers were assumed to be transitioning into the travel lane. From this data sample there was one encroachment for the 12 ft. TWLTL, and two encroachments each for the 14 ft. and 16 ft. TWLTL. After looking at all of the trajectories for the 12 ft. TWLTL it was apparent that most of the 30 participants stayed within the middle of the TWLTL or favored the left side of the lane (relative to the direction of travel). This is not surprising for narrower lanes because drivers can judge distances better on the left side of the vehicle because of their position in the vehicle. For the 14 ft. and 16 ft. TWLTLs, the participants gravitated more towards the right side of the lane for the 14 ft. and 16ft. TWLTLs. Trajectories within the refuge area for the 12, 14, and 16 ft. TWLTL widths can be seen in Figure 4-18. From these images, the variation in lane position and maneuverability clearly increased as the TWLTL lane width increased. Note that the red reference lines begin with the right-most trajectory and are the same length in each of the images in Figure 4-18. It is evident from this figure that the participants were more cautious and controlled when turning into the smaller 12 ft. TWLTL width to prevent any collisions. As the TWLTL width increased the participants tended to utilize more of the TWLTL width as they made their left turn.



A (12 ft.) B (14 ft.) C (16 ft.)

Figure 4-17: Vehicle trajectories for second 3T turn



A (12 ft.) B (14 ft.) C (16 ft.)

Figure 4-19: Vehicle trajectories for second 3T turn refuge area

5 CONCLUSION

The purpose of this Phase B driving simulator study was to evaluate the effects of different lane and shoulder width combinations, as well as the effects of different TWLTL widths on driver performance. Lane and shoulder width combinations were examined based on lateral position and out of lane encroachments, while maneuverability and gap acceptance were evaluated for the TWLTLs. The aim of this study is to produce research justifiable minimum design criteria, standards and recommendations for SCDOT engineers and their design consultants regarding which lane, shoulder and TWLTL widths can be applied to roadways to maintain safe and effective operations.

The main goal of the overall research (Phase A and B) is to determine the influence that flexible lane width standards have on the safety and operation of roadways in South Carolina. After the completion of the field studies in Phase A of this study, limited site characteristics made it impractical to study a variety of lane widths through field data collection. Thus, a driving simulator study was developed to enable a controlled comparison of lane, shoulder, and TWLTL widths. Before commencing the study, an extensive literature review was completed to gain knowledge on previous driving simulator studies and to aid in the design of this study. Immense care was taken during the development of the custom design to ensure that sufficient comparative research regarding the SCDOT's inquiries was implemented throughout the study. The Phase B simulator study produced additional findings and recommendations with regard to the ultimate goal of using flexible lane width standards in South Carolina. The conclusions will refer back to the study objectives to determine the:

1.) Effect lane and shoulder width combinations have on driver performance.
2.) Effect of curves on lane position for various lane and shoulder width combinations.
3.) Operational performance (gap acceptance and maneuverability) of TWLTLs for minimum and maximum widths.

5.1 Effect of lane and shoulder width combinations on driver performance

Driver performance was measured by assessing the percent time out of lane and number of out of lane encroachments. These measurements were evaluated for three lane and shoulder width combinations (a 12 ft. lane width and no shoulder, a 12 ft. lane width with a 2 ft. paved shoulder, and a 10 ft. roadway with a 2 ft. paved shoulder). There was very little difference between the two 12 ft. roadway combinations. A total of 5 participants went out of the lane for the 12 ft. roadway with no shoulder and 7 participants drove out of the lane for the 12 ft. roadway with a 2 ft. shoulder. One important consideration is that lane encroachments with no shoulder can be more severe in the real world – especially if there is a significant pavement edge drop off. However, for the 12 ft. lane width and no shoulder, only one encroachment was to the outside edge, therefore only this one exceeded the boundaries of the shoulder.

A larger difference was seen between the two 12 ft. lane combinations when the total number of encroachments was calculated. The 12 ft. roadway with no shoulder had 6 encroachments while the 12 ft. roadway with a 2 ft. paved shoulder had 13 encroachments. The increase in encroachment numbers with the added shoulder is likely a function of the additional space. In previous studies it has been found that providing extra paved space evokes a sense of security and safety as there is more room for error and corrections. It is noteworthy that none of the shoulder encroachments went beyond the shoulder.

Results from the 10 ft. lane combination show increased effects. The limited lane width scenario had a total of 14 participants drive out of the lane boundary with 28 encroachments. Due to the reduction in lane width it was expected that the drivers would have the most difficulty with this combination. There was also a difference in the general lane position for the 10 ft. lane width. The average lane position values for both of the 12 ft. lane width scenarios were to the left (-.212 ft. for the 12 ft. roadway with no shoulder, -.100 ft. for the 12 ft. roadway with a 2 ft. shoulder). Only the 10 ft. lane width had an average lane position toward the outside edge of the road at 0.149 ft.

One interesting finding of the Phase B study with regard to encroachments is that most of the encroachments that occurred happened on curve sections. Only 2 drivers (out of 60) encroached on straight sections and these encroachments only went into the 2 foot shoulder. Overall, the drivers only experienced one encroachment which left the paved portion of the roadway/shoulder. While the 10 ft. lane width did have increased encroachments, these were all within the bounds of the 2’ paved shoulder. These results also support the Highway Safety Manual analysis conducted in Phase A, showing that there is only a 0.2 total crash per mile difference between the three combinations tested in the driving simulator, see Table 5-1.

Table 5-1: Highway Safety Manual predictions for multiple lane/shoulder width combinations

5,000 AADT and 1 mile with base conditions						
Lane (ft)	10	10	11	11	12	12
Shld (ft)	2	4	1	3	0	2
Total Crashes	1.8	1.7	1.7	1.6	1.7	1.6
F/I Crashes	0.6	0.5	0.5	0.5	0.6	0.5
PDO Crashes	1.2	1.2	1.1	1.1	1.2	1.1

5.2 Effect of curve radii on lane keeping and encroachments

The numbers of encroachments were also evaluated based on the curve radii. All of the curve radii in the three scenarios were split into three categories of small, medium and large. The small curves fell in the range of 900- 1230 ft. Curves within the range of 1231-1500 ft. were recognized as medium and large curves were between 1501-5500 ft. Based on these ranges and the radii of the curves given in the scenarios, almost 45% of encroachments were experienced on the small radii curves, and over 75% were on small and medium curves. Curves to the left were also more involved in encroachments than curves to the right. To combat the effect of curves, curve widening and increased clear zones in curve sections (particularly on curves to the left) can be used to mitigate issues associated with the use of narrower lanes.

5.3 Operational performance (gap acceptance and maneuverability) of TWLTLs widths

For the TWLTL driver simulator study, gap data was collected for two 3T and 5T left turns. TWLTL widths of 12, 14 and 16 ft. were tested for 3T and 5T sections. Based on the average gap, many comparisons were made to determine if the TWLTL width had any effect upon gap acceptance. First, the average gaps for all turns in the 3T sections per scenario were compared between each other. Results from the analysis found no significant gap difference between any of the scenarios, thus indicating that there was no effect on gap acceptance due to the TWLTL width. Another comparison was made by separating the gap data by the order in which the scenarios were driven. To be specific, this grouped gap data by participant's first, second and third scenario driven. These averages were 5.88 s for the first scenario, 5.08 s for the second and 4.90 for the last. Analyses indicated a significant difference between the first and second scenario and the first and last scenario, but not between the second and third scenarios. This indicates that the participants drove more cautiously for the first scenario as they were unaccustomed to the scenario layout and the left turn maneuver into the center lane. As each scenario had two turns, additional comparisons were made to determine if there was a difference between the first and second turn. These differences were statistically significant as the majority of the participants accepted smaller gaps for the second turn than the first. This further indicates that the first turn was used as a learning opportunity.

The 5T turns were also analyzed separately. The average gaps were 4.5s for the 12 ft. TWLTL, 4.8 s for the 14 ft. TWLTL and 4.6s for the 16 ft. TWLTL. Similar to the 3T results the comparison analysis for the 5T sections revealed no significant difference between scenarios. Overall, the TWLTL width had no effect upon gap acceptance. The only effect found was due to the order, first second and third, in which participants drove the scenarios.

Additional analyses were performed to test how the TWLTL width affected participants' ability to maneuver into and within the TWLTL when they performed their left turn. For this portion of the analysis, vehicle trajectories were drawn for 30 participants' second 3T turn in each scenario. The variation in lane position and maneuverability clearly increased as the TWLTL lane width increased. The participants were more cautious and controlled when turning into the smaller 12 ft. TWLTL width. As the TWLTL width increased the participants tended to utilize more of the TWLTL width as they made their left turn. Few indications of encroachments to the travel lanes were detected, and those that were detected were corrected by the driver in most cases.

5.4 Age comparisons

Driver characteristics pertaining to age were also tested in relationship to gap acceptance. Results found that for each scenario the average gap accepted for older participants was higher than the average gap accepted by younger participants. The overall averages of 4.82 s for young and 5.23 s for the older participants were found to be statistically significant. Similar to the Yan et al. study, these results found that older drivers drive more conservatively.

5.5 Recommendations

SCDOT's HDM primarily uses a 12 ft. lane width for rural two- lane arterials and a range of 11-12 ft. for rural two-lane collectors. Results from Phase A of the research encourage the use of AASHTO standards that include 11 to 12 ft. lane widths for rural two-lane arterials and 10 to 12 ft. lane widths for rural two-lane collectors. Findings from the simulator study also encourage the use of 10 to 12 ft. lane widths on rural two- lane roadways in South Carolina. Recommendations from Phase A, also advised that a 10 ft. lane width only be used on a roadway with a speed limit of 40 miles per hour or less. Results from the simulator study agree with this recommendation as a larger effect due to the narrower lane width was seen at a 50 miles per hour speed limit. As there was a high of 28 encroachments for the 10 ft. roadway, it is also advised that a 2 ft. paved shoulder always be present when a 10 ft. lane is implemented. To compensate for the narrow lane width the 2 ft. shoulder provided additional space for the participants to maneuver. As previously stated, the 2 ft. paved shoulder aided in preventing any roadside encroachments from occurring. While the 12 ft. roadway with no paved shoulder experienced the least amount of encroachments it is important to observe the risk associated without having a shoulder. Any roadside encroachments on this type of roadway cause drivers to encounter a pavement drop off into the grass in which there is a larger risk for loss of control and a crash. As seen in Figure 5-1, roadway departures are the leading cause of fatalities in South Carolina. Due to these potential risks, it is best to use a 10 ft. to 12 ft. roadway with a 2 ft. shoulder for roadways in South Carolina. In a case in which a 12 ft. roadway with no shoulder is the best option it is imperative that the roadside be maintained.

Based on findings from the driver simulator research, additional changes are identified for the SCDOT Highway Design Manual (HDM). Recommendations are primarily focused on Chapter 20, Rural Highways, and Chapter 21, Suburban/Urban Streets, however other HDM chapters that are referenced to criteria provided in these chapters would also need to be changed or modified. Proposed changes and modifications, from Phase A and B research findings, are summarized in Tables 5.2, 5.3 and 5.4.

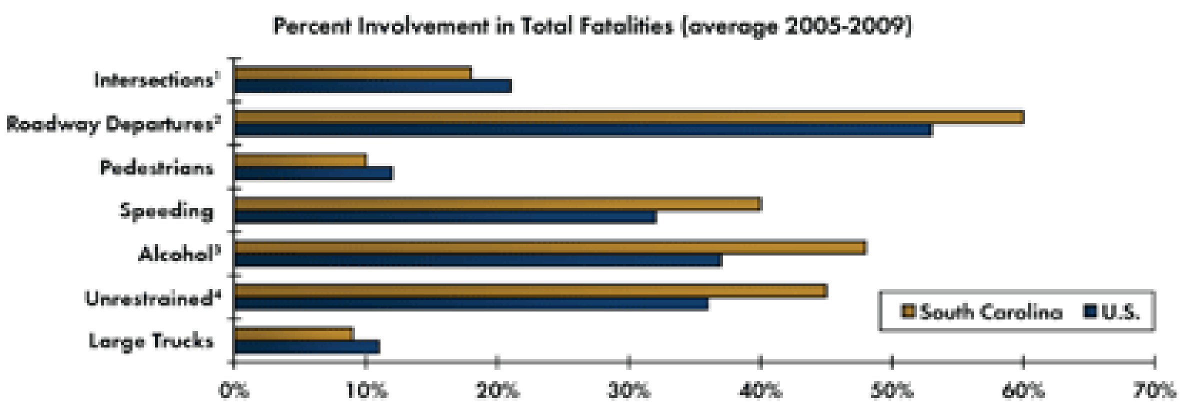


Figure 5-1: South Carolina fatalities comparisons

Additional analyses from the simulator study were performed to determine the effects of TWLTL width on gap acceptance and on turning vehicle encroachments into through lanes. Several ANOVA tests found that the tested TWLTL widths of 12 ft., 14ft. and 16 ft. had no effect upon gap acceptance for the 3T and 5T sections. Trajectories were drawn for 30 participants' second 3T turn to evaluate the effect TWLTL width had on vehicle encroachments into through lanes. Moreover, these results found very little difference between the three widths of 12, 14 and 16 ft. The results defied the prediction that more encroachments would occur in the smaller lane width of 12 ft. For the 30 participants there was one encroachment for the 12 ft. TWLTL and two encroachments for the 14 ft. and 16 ft. TWLTL widths. More lane position variation was found for the larger TWLTL widths as participants took advantage of the larger space for maneuvering. Based on these findings it is recommended that 12, 14 and 16 ft. TWLTL widths can be used in South Carolina. Currently the SCDOT HDM uses 15 ft. TWLTL widths. As there were no major differences in driver behavior for the TWLTL widths tested in the simulator it is recommended that 12 to 16 ft. TWLTL widths can be used in South Carolina. See corresponding recommended TWLT width changes to SCDOT HDM, including a summary of both Phase A and B research findings, in Table 5.5.

Table 5-2: Summary of Phase A and B Research Findings and Recommendations with Proposed SCDOT HDM Changes for Rural Arterials and Collectors, Two-Way Left Turn Lanes

Research Phase	Functional Class	SCDOT HDM Reference	Variable	Existing Values in HDM	Summary of Proposed Changes	Basis for proposed HDM change
A	Rural Two-Lane Arterials	Fig. 20.1D, Footnote 1 (HDM 13.2.3)	Travel Lane Width	12 ft.	11-12 ft. (see criteria in Table 5-3)	Research results, AASHTO, other DOT's, Harwood et al, 2000
B	Rural Two-Lane Arterials	Fig. 20.1D, Footnote 1 (HDM 13.2.3)	Travel Lane Width	12 ft.	10-12 ft. (see criteria in Table 5-3)	Research results from Clemson driver simulator
A	Rural Two-Lane Arterials	Fig. 20.1D (HDM 21.2.7)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Rural Two-Lane Arterials	Fig. 20.1D (HDM 21.2.7)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No observed effect on gap acceptance or driver behavior, 12 ft. min. width acceptable
A	Rural Two-Lane Collectors	Fig. 20.1E, Footnote 1 (HDM 13.2.3)	Travel Lane Width	11-12 ft.	10-12 ft. (see criteria in Table 5-4)	Research results, AASHTO, other DOT's, Harwood et al, 2000
B	Rural Two-Lane Collectors	Fig. 20.1E, Footnote 1 (HDM 13.2.3)	Travel Lane Width	11-12 ft.	10-12 ft. (see criteria in Table 5-4)	Research results from Clemson driver simulator
A	Rural Two-Lane Collectors	Fig. 20.1E (HDM 21.2.7)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Rural Two-Lane Collectors	Fig. 20.1E (HDM 21.2.7)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No observed effect on gap acceptance or driver behavior, 12 ft. min. width acceptable

It should be noted that travelway widening on horizontal curves was verified to be an important roadway design element as for all scenarios tested results from the driver simulator provided evidence of considerably more encroachments along curved roadway sections. SCDOT HDM Figure 11.2F provides values for travelway widening. The importance of adhering to these threshold criteria was evident in results from the driver simulator research for passenger vehicles, and not just truck design vehicles.

Table 5--3: Summary of Phase A and B Research Findings and Recommendations for Proposed Travel Lane Width Criteria for Rural Two-Lane Arterials

Research Phase	**Travel Lane Width (*)**	**Criteria and Conditions**
A	11 ft. min., 12 ft. desirable	Design Speed 55 mph or less, assuming a 2 ft. paved shoulder, if shoulder width does not meet minimum requirements, use 12 ft. min
A	12 ft. min.	Design Speed 60 mph or greater
B	10 ft.	Min. 2 ft. paved shoulders should be provided for all roadway applications
B	12 ft.	Min. 2 ft. paved shoulders desirable, or satisfactory roadside maintenance
B	10 ft.	Design speed 40 mph or less

*** Footnotes:**

1. If lower design speeds are allowed, narrower travel lane widths could be acceptable, 10 ft. min.
2. For industrial areas or locations with higher heavy vehicle use, 12 ft. lanes should be used.
3. Criteria for Travel Lane Width assumes no problematic prior crash histories related to lane width including run off the road, sideswipe (same and opposite direction), head-on crashes.
4. Under no condition should travel lane widths be less than 10 ft. min.
5. As identified in SC HDM Figure 11.2F, criteria for travelway widening on horizontal curves should be accommodated for 12 ft., 11 ft. and 10 ft. travel lanes.

Table 5--4: Summary of Phase A and B Research Findings and Recommendations for Proposed Travel Lane Width Criteria for Rural Two-Lane Collectors

Research Phase	Travel Lane Width (*)	Criteria and Conditions
A	10 ft. min.	AADT less than 400 veh./day, design speed 40mph or less
A	11 ft. min.	AADT between 401-2000 veh./day, design speed 50mph or less, assuming a 2 ft. paved shoulder, if shoulder width does not meet minimum requirements, use 12 ft. min
A	12 ft. min.	AADT over 2,000, design speed 60 mph or greater
B	10 ft.	Min. 2 ft. paved shoulders should be provided for all roadway applications
B	12 ft.	Min. 2 ft. paved shoulders desirable, or satisfactory roadside maintenance
B	10 ft.	Design speed 40 mph or less

***Footnotes:**

1. If lower design speeds are allowed, narrower travel lane widths could be acceptable, 10 ft. min.
2. For industrial areas or locations with higher heavy vehicle use, 12 ft. lanes should be used.
3. Criteria for Travel Lane Width assumes no problematic prior crash histories related to lane width including run off the road, sideswipe (same and opposite direction), head-on crashes.
4. Under no condition should travel lane widths be less than 10 ft. min.
5. As identified in SC HDM Figure 11.2F, criteria for travelway widening on horizontal curves should be accommodated for 12 ft., 11 ft. and 10 ft. travel lanes.

Table 5--5: Summary of Phase A and B Research Findings and Recommendations with Proposed SCDOT HDM Changes for Urban/Suburban Arterials and Collectors, Two-Way Left Turn Lanes

Research Phase	Functional Class	SCDOT HDM Reference	Variable	Existing Values in HDM	Summary of Proposed Changes	Basis for proposed HDM change
A	Five-Lane Urban Street (with Shoulders)	Fig. 21.2B (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Five-Lane Urban Street (with Shoulders)	Fig. 21.2B (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No simulator observed effect on gap acceptance or driver behavior, 12 ft. min. acceptable
A	Five-Lane Urban Street (Curb and Gutter)	Fig. 21.2C (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Five-Lane Urban Street (Curb and Gutter)	Fig. 21.2C (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No simulator observed effect on gap acceptance or driver behavior, 12 ft. min. acceptable
A	Suburban/Urban Multilane Arterials	Fig. 21.3A (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Suburban/Urban Multilane Arterials	Fig. 21.3A (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No simulator observed effect on gap acceptance or driver behavior, 12 ft. min. acceptable
A	Suburban/Urban Collectors	Fig. 20.1E (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	11-16 ft.	Research results, AASHTO, other DOT's, Gattis et al, 2010
B	Suburban/Urban Collectors	Fig. 20.1E (HDM 21.2.7.2)	TWLTL Lane Width	15 ft.	12 ft., 14 ft., 16 ft.	No simulator observed effect on gap acceptance or driver behavior, 12 ft. min. acceptable

***Footnotes:**

1. If lower design speeds are allowed, narrower TWLTL widths could be acceptable, 11 ft. min.
2. For industrial areas or locations with higher heavy vehicle use, 15 ft. TWLTL lanes should be used.
3. Criteria for Travel Lane Width assumes no problematic prior crash histories potentially related to TWLTL lane width including sideswipe (same and opposite direction), and head-on crashes.
4. Wider TWLTL widths should be used in areas of high driveway density.

As previously stated, field studies were conducted in 2011 to evaluate the effect different roadway combinations and TWLTL widths had on driver behavior. Due to the limited sample size of roadways with specific attributes from these studies additional research needed to take place. By using the driving simulator our research team was able to directly focus on context sensitive roadways in South Carolina. From the simulator results, additional evidence was provided backing up the recommendations made from the field studies in Phase A. The combined results from both studies indicated that lane widths of 10 to 12 ft. were acceptable for rural two-lane roadways in South Carolina. The simulator study also found that specific combinations of a 12 ft. roadway with no shoulder, 12 ft. roadway with a 2 ft. shoulder and a 10 ft. roadway with a 2 ft. shoulder are optimal options, however it is imperative to provide satisfactory roadside maintenance when a paved shoulder is not provided. Additional results from both studies found that 12 to 16 ft. TWLTL widths were acceptable. Together, results from the field and simulator study succeeded in recommending flexible lane width standards for the SCDOT.

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APPENDIX A: Traffic Intervals Programmed into Sim for Gap Acceptance Tests

3T

["1.5" "3.5" "3.5" "4.0" "4.0" "5.0" "6.0" "4.5" "7.0" "3.0" "4.5" "4.5" "6.0" "8.0" "4.5" "5.0" "6.0" "4.0" "7.0" "4.5" "4.0" "5.0" "3.5" "4.0" "5.0" "3.0" "3.5" "3.5" "4.0" "4.0" "5.0" "6.0" "4.5" "7.0" "3.0" "4.5" "4.5" "6.0" "8.0" "4.5" "5.0" "6.0" "4.0" "7.0" "4.5" "4.0" "5.0" "3.5" "4.0" "5.0"]

5T

Left Lane ["1.5" "7.0" "8.0" "11.0" "6.5" "7.0" "7.5" "10.5" "12.5" "11.0" "11.0" "8.5" "8.5" "9.0" "8.5" "8.5" "10.0" "6.5" "9.5" "8.0" "10.5" "9.0" "8.0" "10.5" "10.0" "13.0" "7.0" "3.0" "7.0" "8.0" "11.0" "11.5" "7.5" "10.5" "12.5" "11.0" "11.0" "8.5" "8.5" "9.0" "8.5" "8.5" "10.0" "6.5" "9.5" "8.0" "10.5" "9.0" "8.0" "10.5" "10.0"]

Right Lane [list "5.0" "7.5" "9.0" "10.5" "2.0" "10.0" "9.0" "14.0" "9.5" "10.0" "11.5" "9.0" "7.5" "10.0" "7.0" "11.0" "7.0" "7.5" "9.0" "10.0" "11.0" "6.5" "10.0" "10.0" "11.5" "11.0" "2.5" "6.5" "7.5" "9.0" "10.5" "10.0" "9.0" "14.0" "9.5" "10.0" "11.5" "9.0" "7.5" "10.0" "7.0" "11.0" "7.0" "7.5" "9.0" "10.0" "11.0" "6.5" "10.0" "10.0" "11.5"]

5T Effective Gaps

[list "3.27" "3.5" "3.5" "4.0" "4.0" "5.0" "6.0" "4.5" "2.0" "2.0" "7.0" "3.0" "4.5" "4.5" "6.0" "8.0" "4.5" "5.0" "6.0" "4.0" "7.0" "4.5" "4.0" "5.0" "3.5" "4.0" "5.0" "5.0" "3.5" "3.5" "5.0" "6.0" "4.0" "3.0" "3.5" "4.0" "5.5" "3.5" "4.5" "5.5" "5.0" "6.0" "3.0" "3.5" "4.5" "5.5" "5.0" "5.0" "5.0" "6.5"]

APPENDIX B; Curve Boundaries

Scenario 1 and 2

Straight 1		
	Start	End
	2701.5	2702.1
	14700.9	15195.4
	4	0

Curve 1		
	Start	End
	2677.8	2702.2
	14534.7	14683.5
	6	4

Curve 2		
	Start	End
	2656.9	2661.3
	14272	14488.6
	14.5	6

Straight 3		
	Start	End
	2701.5	2663.1
	14155	14254.1
	14	14.9

Curve 5		
	Start	End
	2642.5	2652.4
	13261.1	13453.3
	1.7	-1.9

Curve 3		
	Start	End
	2730	2708.6
	14010.4	14134.3
	10	13.4

Straight 4		
	Start	End
	2731.8	2730.1
	13784.2	13984.8
	7.4	10.2

Curve 4		
	Start	End
	2713.6	2732.5
	13615	13758.9
	0.2	6.6

Straight 5		
	Start	End
	2661.2	2707
	13476.8	13597.1
	-2	-0.2

Curve 6		
	Start	End
	2688.4	2680.3
	13005.4	13122.3
	8.3	4

Straight 6		
	Start	End
	2671.8	2649.9
	13154.4	13233.9
	3	2

Curve 7		
	Start	End
	2701.8	2677.4
	12737.7	12899.5
	12.2	9

Scenario 3

Straight 13		
	Start	End
	2701.7	2701.7
	15047.8	15195.9
	0	0

Curve 12		
	Start	End
	2715.3	2751.5
	14377.5	14596.7
	10.6	8.1

Curve 13		
	Start	End
	2716.3	2701.7
	14814.2	15018.8
	0	0

Curve 11		
	Start	End
	2667.4	2668.9
	13996.8	14297.2
	0.5	7.7

Straight 12		
	Start	End
	2748.5	2721.7
	14616	14780.2
	7.3	0

Straight 10		
	Start	End
	2715.6	2673.9
	13910.9	13985.3
	0	0.3

Curve 10		
	Start	End
	2736.8	2725
	13618.4	13892.8
	8.4	0.1

Straight 8		
	Start	End
	2693.9	2669.6
	13044.9	13291
	15.8	19

Curve 9		
	Start	End
	2667.4	2687.6
	13315.9	13493.1
	19	15.3

Curve 8		
	Start	End
	2697.2	2697.6
	12810.1	13011.7
	13.7	15.4

Appendix C: Script to Conduct Experiment

Note: During transitions between sessions it is important NOT to say things such as "good job", "bad job", or anything of this reinforcing nature

Pre-participant

- Consent Form
- Motion Sickness Forms
- Make sure puke can is by car and empty
- Sim Data Forms

Welcome—if you have a cell phone please make sure it is turned off before we begin. Please note that I will be reading from a script throughout the experiment, and I may not be able to answer certain questions that pertain to the experiment until after we have completed the study.

- Place experiment in progress sign on door.
- Thank you for choosing to participate in our study. Before we get started please read and sign this consent form. Should you have any questions, please feel free to ask. After you have read it, please initial the bottom of the pages and sign and date the back page. If you would like a copy of the signed consent form for your records, just let me know.
- The purpose of this study is to investigate driving behavior in various settings.
- Before we get started I am going to ask you some motion sickness questions. I will ask you these same questions after each time you drive today. If you feel uncomfortable at any time during the experiment, please let me know immediately.
- Before we get started we will also be taking a few minutes to take your blood pressure.

- Ask Motion Sickness Questionnaire and Demographics questions
- Take blood pressure as they are doing the questions

You may now get into the car.

- Please sit in the vehicle and move the seat forward or backward so that it suits you.
- Show car controls
- The controls work just like a regular automatic transmission vehicle: the gas is on the right, and the brake is on the left. The car should already be in park, so please do not change gears as the car is already in drive.
- The steering is quite loose and sensitive, meaning the vehicle reacts as if it has too much power steering.
- You will now have several practice sessions to get used to the vehicle and the simulator.
- Once you see the road you may start driving. Your goal for today will be to drive through the scenarios as you would in your own vehicle.
- If you start to feel uncomfortable or uneasy at any time please tell me immediately.
- I will tell you when to begin each scenario.

*Load "*1LaneKeeping_Straight*"*

➢ Enter participant number then "#_LWst"

For your first practice session:

- *(Please wait for instructions screen-Press A Scenario shows up)* You will drive on a straight road to familiarize yourself with the vehicle for two 30 second periods.
- (*Press A- Dots show up*) On the screen you can see five dots. These dots will tell you where you are in the lane to help you get a feel for the car.
- (Press A) The green dot appears if you are in the middle of the road.
- (Press A) This yellow dot indicates that you are driving in the left side of the lane.
- (Press A) The red dot shows that you are out of the lane.
- (Press A twice) This yellow dot indicates that you are driving along the right edge of the lane.
- (Press A) This red dot shows you are out of the lane to the right. (Press A) All red dots show that you are completely out of the lane."
- (Press A twice) For the first run you can drive at any speed that you feel comfortable. The scenario will cut off in 30 sec. Please move

around inside the lane until you are comfortable with the lane's boundaries.

- (Press A) Now you will get to drive this scenario again for another 30 sec. This time try to maintain the 45 mph speed limit. (Set timer for 30 sec) A voice will also instruct you to slow down if you drive faster than 45 miles per hour. When my timer goes off , lift your foot off the gas, and I will turn off the driving simulator. You may now begin.
- You can repeat practice sessions as many times as necessary to feel comfortable.
- Buzz timer after 30 seconds, wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session

Ask Motion Sickness Questions- Record on Data Sheet

Load "3.Lane Keeping_Curves_DS600"

- ➢ Enter participant number then "#_LWcu"

For your second practice session

- (Please wait for instructions screen-Press A) Now you will practice staying in your lane on a continuously curvy road. It is designed to be difficult for everyone as it is intentionally quite curvy. This time you will not have the dots to show you where you are in the lane.
- A voice will also instruct you to slow down if you drive faster than 50 miles per hour.
- This session will automatically end after you maintained lane position for a minute. When the screen goes black, lift your foot off the gas, and I will turn off the driving simulator.
- You can repeat each practice session as many times as necessary to feel comfortable. (Press A-Car starts) You may begin now.
- At the top of the left screen **record** the number of Departures in the data sheet
- Wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session

Ask Motion Sickness Questions- Record on Data Sheet

- ➢ Take a break. Get participant out of car. Offer restroom break.

*Load "*5.Stopping_DS600*"*

- ➢ Enter participant number then "#_LWstop"

For your third practice session

- (Please wait for instructions screen) -You will practice stopping. (Press A- Scenario shows up) For this scenario you will have to do 5 complete stops at a series of stop signs and lights. A voice will tell you to slow down if you drive faster than the posted speed limit. Throughout the scenario you will only drive straight. After each stop proceed through the intersection.
- (Press A-car starts up) You may now begin
- (On the left screen you can see how far the subject gets to the stop bar line, negative means behind the line, positive is they are past the stop bar-**record** these values in data sheet)
- (After they go through last intersection)You have now completed 5 stops so go ahead and stop the car and place it in park. (Stop the scenario)
- Wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session

Ask Motion Sickness Questions- Record on Data Sheet

- ➢ Make participant get out of car. Offer restroom break. (They must get out after this scenario

*Load "*6.Left turns_DS600*"*

- ➢ Enter participant number then #_LWleft"

For your fourth practice session

- (Please wait for instructions screen) –Now you will practice making left turns.
- (Press A- Scenario shows up) For this scenario you will make 6 left turns. For the first turn the simulator will control your speed in order to show you how to do a left turn. While this is happening you will need to push on the gas.

- A voice will tell you to slow down if you drive faster than the posted speed limit. At the end when the screen goes black put the car in park.
- (Press A- Start car) You may now begin.
- (On the left screen you can see the number of left turns the subject has made)
  --the scenario will automatically turn black when they have completed all turns
- Wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session

Ask Motion Sickness Questions- Record on Data Sheet

- ➢ Take a break. Get participant out of car. Offer restroom break.

Load "7.Right Turns_DS600"

- ➢ Enter participant number then "#_LWright"

For your fifth and final practice session

- (Please wait for instructions screen-Press A)You will practice making right turns. For this scenario there will be a total of 4 right turns. For the first turn the simulator will control your speed in order to show you the correct way of making a right turn. A voice will also instruct you to slow down if you drive faster the posted speed limit.
- (Press A- Start the car) You may now begin.
- (When they get to second turn) For this second turn you will have a bit more control on your speed but still not full control as the simulator will guide you.
- (Third turn) Tell them they can make a right on red
- (After they complete four right turns)- You have now completed all right turns, stop the car and put it in park.
- Wait for them to lift foot off of gas and stop scenario
- Collect Data for this Practice Session

Ask Motion Sickness Questions- Record on Data Sheet

- ➢ Take a break. Get participant out of car. Offer restroom break.
- ➢ Give Phase A of questionnaire

- *Look at the order in which the three scenarios need to be driven on the **Data Sheet**. Enter subject name as follows*
- *Participant #_LW(Scenario #)_# indicating the order driven*
    - *For Scenario 1: #_LW1_#*
    - *For Scenario 2: #_LW2_#*
    - *For Scenario 3: #_LW3_#*

CONDITION 1

Load "LaneWidth_#"

- Enter participant number then "#_LW#_1"

Now that you have completed the practice sessions, we will begin the actual study. It is important that you drive as you would in your own vehicle. In the beginning of the scenario try to maintain the posted speed limit. A voice will tell you if you are going too fast or too slow. Throughout the scenario you will also be doing a series of left turns. For these turns, turn left into the two way left turn lane and stop until all cars on your right have passed. Please be sure to listen to all of the voice commands in the simulator. This scenario should take about 10 minutes. You may now begin.

Ask Motion Sickness Questions- Record on Data Sheet

- Make participant get out of car
- Offer snack
- Complete part 2 of questionnaire

CONDITION 2

Load "LaneWidth_#"

- Enter participant number then "#_LW#_2"

It is important that you drive as you would in your own vehicle. In the beginning of the scenario try to maintain the posted speed limit. A voice will tell you if you are going too fast or too slow. Throughout the scenario you will also be doing a series of left turns. For these turns, turn left into the two way left turn lane and stop until all cars on your right have passed. Please be sure to listen to all of the voice commands in the simulator. This scenario should take about 10 minutes. You may now begin.

Ask Motion Sickness Questions-Record on Data Sheet

- Make participant get out of car
- Complete part 3 of Questionnaire
- Measure Blood Pressure

CONDITION 3

Load "LaneWidth_#"

- Enter participant number then "#_LW#_3"

It is important that you drive as you would in your own vehicle. In the beginning of the scenario try to maintain the posted speed limit. A voice will tell you if you are going too fast or too slow. Throughout the scenario you will also be doing a series of left turns. For these turns, turn left into the two way left turn lane and stop until all cars on your right have passed. Please be sure to listen to all of the voice commands in the simulator. This scenario should take about 10 minutes. You may now begin.

- Ask Motion Sickness Questions-Record on Data Sheet
- Have person get out of car and sit at table
  - Ask "what do you think was the purpose of this study?"
  - Ask post questions on page 4 of Data Sheet
  - Take Blood Pressure
- Pay participant

Thank you for participating in this research study

- Remember that the purpose of the study was to investigate driving behavior in various settings.
- Complete Master subject list "success" column now.
- Email bmaleck@g.clemson.edu with attendance/success information.
- *Backup data to external hard drive*

Appendix D: Participant Data Sheets

Participant Number: _______________

Date: _______________

Experimenter: ________________________

Did you give participant their copy of the consent form? Yes or No

Did you file the signed consent form? Yes or No

<u>Ask prior to running experiment:</u>

- Do you have a valid US driver's license? ______________
- Age _______
- Age Group – Young (18-34) / Middle (35- 65) / Old (65+)
- Gender _______
- Years driving ____
- Are you a resident of SC? Yes / no
- Do you have a past history of motion sickness?__________
- Do you have a past history of migraines?________
- Do you have any vision problems?_________

Participant Number:								
	Perform Blood Pressure Test ______ ______ ______ ______ ______							
Completed	**Scenarios**	**Nausea Questions** Answer each question on a scale from 0 to 10 where 0 is "not at all" and 10 is "severely."						**Comments**
		Sick to your stomach	**Sweaty**	**Light headed**	**Nauseous**	**Hot/warm**	**Dizzy**	
	1.) Straight							
	2.) Curvy Edge touches _________							
	3.)Stopping Distance to stop bar 1.) _____ 2.) _____ 3.) _____ 4.) _____ 5.) _____							
	4.) Left Turns							
	5.) Right Turns							

	Questionnaire							
Participant Number:								
Completed	**Scenarios**	**Nausea Questions** Answer each question on a scale from 0 to 10 where 0 is "not at all" and 10 is "severely."						**Comments**
		Sick to your stomach	**Sweaty**	**Light headed**	**Nauseous**	**Hot/warm**	**Dizzy**	
	LaneWidth_1 _______							
	Questionnaire							
	LaneWidth_2 _______							
	Questionnaire							
	LaneWidth_3 _______							
	Perform Blood Pressure Test _______ _______ _______ _______ _______							
	Ask Purpose of the study							
	Fill out master subject list							
	Email status to Brian: bmaleck@g.clemson.edu							

Participant Number: _______________

<u>Ask at end of experiment:</u>

- Estimate the number of miles you drive each year _______
- How many days do you drive each week _______
- What kind of vehicle do you drive? Make____ Model____ Year ____
- Have you been in a crash in the last year while driving? Yes / no
- Have you been in a crash in the last 5 years while driving? Yes / no
- Were you considered at fault in any of these crashes? Yes / no
  If Yes, how many? _____
- Have you received a speeding ticket in the last year? Yes / no
- Have you received a speeding ticket in the last 5 years? Yes / no
- Do you typically wear your seatbelt? Yes / no
- Do you ever talk on your cell phone when you drive? yes / no
- Do you ever text message when you drive? Yes / no

Appendix E: Participant Data

Participant #	Age Group	Completed
1	Young	Yes
2	Young	Yes
3	Young	Yes
4	Young	No- Sim sick
5	Young	Yes
6	Middle	Yes
7	Young	Yes
8	Young	Yes
9	Young	Yes
10	Young	Yes
11	Young	Yes
12	Young	Yes
13	Middle	Yes
14	Young	Yes
15	Young	Yes
16	Young	Yes
17	Young	Yes
18	Young	No- Sim sick
19	Young	No- Sim sick
20	Young	Yes
21	Young	Yes
22	Young	Yes
24	Young	Yes
25	Young	Yes
26	Young	No- Sim sick
23	Young	No- Sim sick
27	Young	Yes
28	Young	Yes
29	Young	Yes
30	Young	Yes
31	Young	Yes

32	Young	Yes
33	Middle	Yes
34	Middle	Yes
35	Young	Yes
36	Middle	Yes
37	Middle	No- Sim sick
38	Middle	Yes-Little sick
39	Young	Yes
40	Young	Yes
41	Young	Yes
42	Young	Yes
43	Young	Yes
44	Middle	Yes
45	Young	No- Sim sick
46	Young	Yes
47	Young	Yes
48	Middle	Yes
49	Middle	Yes
50	Middle	Yes
51	Young	Yes
52	Young	Yes
53	Middle	No- Sim sick
54	Young	Yes
55	Middle	Yes
56	Middle	No- Sim sick
57	Middle	No- Sim sick
58	Middle	Yes
59	Young	Yes
60	Middle	Yes
61	Middle	Yes
62	Middle	Yes
63	Middle	Yes
64	Middle	Yes
65	Middle	Yes
66	Middle	Yes
67	Middle	No

68	Young	Yes
69	Middle	No- Sim sick
70	Middle	Yes
71	Young	Yes
72	Young	Yes

Appendix F: Post Question Results on Driving Behavior

Estimate the number of miles you drive each year.

How many days do you drive each week?

Age group	Avg. Age	Avg. Yrs Driving	Avg. Miles/ Yr
Young	21	5.5	11000
Middle/Old	49	31.5	14000

Have you been in a crash in the last year (5 years) while driving?

Age group	Crash -1 yr	Crash-5 yr
Young	2	10
Middle/Old	1	6

Have you received a speeding ticket in the last year (5 years)?

Age group	Ticket -1 yr	Ticket-5 yr
Young	13	26
Middle/Old	1	6

Do you talk on your cell phone while driving?

Cell Phone	Young	Middle/Old
Yes	32	12
No	8	8

Do you text message while driving?

Text Messaging	Young	Middle/Old
Yes	11	4
No	29	16