5-2015

Assessment of Crash Location Improvements in Map-Based Geocoding Systems and Subsequent Benefits to Geospatial Crash Analysis

Adika Mammadrahimli
Clemson University

ASSESSMENT OF CRASH LOCATION IMPROVEMENTS IN MAP-BASED GEOCODING SYSTEMS AND SUBSEQUENT BENEFITS TO GEOSPATIAL CRASH ANALYSIS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Civil Engineering

---

by
Adika Mammadrahimli
May 2015

Accepted by:
Dr. Wayne A. Sarasua, Committee Chair
Dr. Jennifer H. Ogle
Dr. Mashrur Chowdhury

ABSTRACT

According to the 2012 South Carolina Traffic Collison Fact Book, a fatality occurs in South Carolina every 10.9 hours and an injury every 16.3 minutes. These rates rank among the highest in the country. Furthermore, South Carolina incurs over two billion dollars in economic loss annually due to road traffic crashes. The South Carolina Department of Transportation (SCDOT) in collaboration with the South Carolina Department of Public Safety (SCDPS), has undertaken a series of initiatives in an effort to reduce the number of vehicle crashes, especially injury and fatal crashes that occur every year in South Carolina. One of these initiatives is the deployment of a map-based crash geocoding system that has greatly improved the quality of the location data. My thesis examines the progression in crash location data quality in South Carolina by reviewing improvements made to crash data collection methods over recent years and analyzing subsequent benefits of having higher quality crash data from a spatial analysis standpoint. Geographic Information System (GIS) analytical tools are used to help assess improvements in geocoding accuracy. A case study evaluation of driveway related crashes, occurring in close proximity to intersections is presented as one of the many benefits of having more spatially accurate crash data.

DEDICATION

I dedicate this thesis to my parents Iftikhar and Zenfira Mammadrahimova and my sister Aytan Mammadrahimli for their support and unconditional love that motivated me to set higher targets for myself and strive to achieve excellence in all I do.

I also dedicate this thesis to my host parents Dianne and Jerry Kinard who took me in as their daughter and placed me in an environment filled with love and encouragement. I am eternally grateful.

ACKNOWLEDGMENTS

First and foremost I want to thank my advisor Dr. Wayne Sarasua, for allowing me to be a part of the team for this project and giving me the opportunity to complete my Masters. I am truly grateful for the support and dedication he has constantly provided for me during this project and throughout my stay at Clemson University.

I also would like to thank Dr. Jennifer H. Ogle and Dr. Mashrur A Chowdhury, for their technical guidance, encouragement and support during my course of study at Clemson.

I would also like to acknowledge my team of hard working students that helped throughout the duration of this project. Completing this study would not have been possible without your hard work and diligence. Thank you Kweku Brown, for all of your help and hard work with data analysis. Additional thanks go out to Andrew Stokes, Kakan Dey, Benton Reed, and Xi Zhao, and recent graduates from D.W. Daniel High School Eram Alam, Elizabeth Dawson, Charlotte Devol, Julie Sarasua, and Jay Sherrill who assisted with the spatial database development. Lastly, I want to give thanks to Dr. Jeff Davis from Citadel and Dr. Nathan Huynh from University of South Carolina for all their help and expertise during the analysis process. Once again I want to thank you all for your dedication and hard work for this project was truly a team effort.

Lastly I want to thank everyone in Clemson ITE Student Chapter who made my stay in Clemson very memorable.

TABLE OF CONTENTS

Page

TITLE PAGE……………………………………………………………………….i

ABSTRACT.. ii

DEDICATION………………………………...…………………………...…....iii

ACKNOWLEDGMENTS...iv

TABLE OF CONTENTS... v

LIST OF TABLES.. vii

LIST OF FIGURES viii

CHAPTER

1. INTRODUCTION 10

Introduction and Problem Statement 10
Research Objective 11
Potential Benefits of This Research.. 12
Thesis Organization 12

Table of Contents (Continued) Page

2. LITERATURE REVIEW……………………………………………….....…13

Evolution of Crash Geocoding and Reporting……………….……..…...13
Use of GIS to Facilitate Crash Analysis………..……………....…….15
Crash Reporting in South Carolina……………………………..…….23
Chapter Conclusion………………………………….…………24

3. SOUTH CAROLINA CRASH DATA EVALUATION AND GEOCODING.. 26

4. ANALYSIS.. 32

GIS Analysis of South Carolina Crash Data.. 32
Proximity Analysis.. 33
GIS Variable Buffer Analysis... 35
Analysis of Driveway Related Crash Data 37
Driveway Buffer Creation... 42

5. CONCLUSION AND RECOMMENDATIONS 56

6. REFERENCES…………………………………………………………58

LIST OF TABLES

Table Page

3.1: Percent of Crash Data by Geocoded Category and by Year.................................... 28

3.2: Percent of Highway Patrol Crash Data Format Categories by Year.......................... 29

3.3: Percent of Highway Patrol Crashes in Wrong County 30

4.1: Average Distance from Reported Route by Year 33

4.2: Percent of Highway Patrol Crash Data Identified by Corridor by Year.................... 36

4.3: Junction Type Coding for Crashes within Driveway Buffers................................... 41

4.4: Percent of driveway Related Midblock Crashes coded as
"intersection" crashes.. 42

4.5: Number of Driveway Crashes Occurring within the Hatched
Area in Figure 4.5 44

4.6: Number of Driveway Crashes Occurring within the Hatched
Area in Figure 4.9 50

4.7: Comparison of driveway crashes occurring within 0-150 ft. and
150-300 ft. of an intersection 53

LIST OF FIGURES

Figure Page

2.1: Segments Shown As 3-D Columns to Show Crash Risk and Grouping…..................16

2.2: Kernel Density Analysis on Pole Crashes In South Carolina……………………….16

2.3: MassDOT interactive Crash Cluster Map.. 18

2.4: Top Crash Intersections 2010-2012... 19

2.5: Top Pedestrian Crash Clusters 2010-2012…………….……………………… ...20

2.6: Top Bicycle Crash Clusters 2010-2012…………………………….……….....….21

2.7: Crash Density and Population Density, 2000-2002……………………………...…22

3.1: Geocoded crashes in South Carolina: a) 2004 all; b) 2012 highway patrol 27

4.1: Rear-End And Angle Crashes on US 25 In Greenville, SC for 2010 (Left) And 2012 (Right)... 33

4.2: Results of the GIS Travelway Buffer Operation Including Corrections. 37

4.3: Driveway Related Crashes Over a Three Year Period on US Highway 1 in Richland County, SC 39

4.4: Driveway Related Crashes Coded as “No Junction” 40

List of Figures (Continued)

Figure Page

4.5: US Highway 176 in Richland County, South Carolina. Boolean Intersection Example 44

4.6: Right In Right Out Driveway Buffers.. 46

4.7: Full Access Driveway Buffers.. 47

4.8: Driveway Influence Buffers Overlayed with 2012 Crashes (Image From Bing Maps).. 48

4.9: US 176 Richland Boolean Intersection Example 50

4.10: US 176 Richland Crashes Occurring Within the 50ft Circle Buffer and Rectangular Buffer………………..……………………………………………….52

4.11: Predicted Crashes vs AADT for Driveways within the 150 Ft. Corner Clearance (Negative Binomial) 55

CHAPTER ONE

INTRODUCTION

1.1 Introduction and Problem Statement

South Carolina has historically been ranked among states with the highest crash fatality rates in the country. In 2010, there were 810 traffic fatalities in South Carolina, resulting in rates of 1.65 fatalities per 100 million vehicle miles traveled (VMT) and 17.2 fatalities per 100,000 population based on the Research and Innovative Technology Administration (RITA) and Fatality Analysis Reporting System (FARS) reviews. Although these rates are the lowest recorded over the past decade in South Carolina, these values are considerably higher than the national averages of 1.1 fatalities per 100 million VMT and 11 fatalities per 100,000 population. The 2010 crash rates in South Carolina were the third and seventh highest rates for fatalities per VMT and fatalities per 100,000 population in the United States. According to the 2012 South Carolina Traffic Collison Fact Book, a fatality occurs in South Carolina every 10.9 hours and an injury every 16.3 minutes. Moreover, South Carolina incurs over two billion dollars in economic loss annually due to road traffic crashes (SCDOT, A Strategic Highway Safety Plan).

Recent efforts by South Carolina Department of Transportation (SCDOT) to reduce vehicle crashes, especially injury and fatal crashes, within the state led to development of the 2003 Strategic Highway Safety Plan (SHSP): The Road Map to Safety. Published in 2007, the SHSP was the result of concerted efforts by SCDOT, South Carolina Department of Public Safety (SCDPS), South Carolina Division Office of the Federal Highway

Administration (FHWA) and other local, state and federal road safety advocacy groups and agencies. Using 2004 as the baseline year, two principal goals were adopted including

1) Reduce traffic fatalities from 1046 in 2004 to 784 or fewer in 2010, and

2) Reduce the number of traffic crash injuries by 3% annually (*SCDOT, A Strategic Highway Safety Plan, 2007).*

An important factor to achieving these goals was purposeful collaboration by SCDOT and SCDPS to improve South Carolina's crash data collection, reporting and processing. Improved crash data helps to improve the reliability of processes such as crash location identification and evaluation of countermeasure effectiveness. Crash data collection is, by far, the most important step in the effort to improve crash data quality. Errors and inaccuracies recorded during this step are propagated through all the other crash data management procedures. The larger the number of entities/agencies involved in the process, the more potential for errors to be introduced into shared crash database files.

1.2 Research Objective

My thesis examines the progression in crash location data quality in South Carolina by reviewing improvements made to crash data collection methods over recent years and analyzing subsequent benefits of having higher quality crash data from a spatial analysis standpoint. Geographic Information System (GIS) analytical tools are used to help assess improvements in geocoding accuracy. This thesis has two objectives:

a) Analyze several years of crash data to identify location problems and accuracy of data

b) Demonstrate how spatially accurate crash data in South Carolina will enhance SCDOT's ability to conduct data-driven transportation safety analysis.

1.3 Potential Benefits of This Research

This research will help illustrate and to what extent that South Carolina's new crash geocoding system has resulted in improved crash positional accuracy. By analyzing the spatial characteristics of the new system, problems can be identified. Further, improved spatially accurate crash data may enhance existing safety initiatives that currently make use of South Carolina's crash data as well as foster new safety related research that could result in more effective safety programs and policies. Another benefit is to facilitate management projects aimed at improving crash-data accuracy and detect unintended consequences that other crash system changes and improvements may have on crash data accuracy *(Crash Data Improvement Guide, 2010).* A case study evaluation of driveway related crashes occurring in close proximity to intersections presented Chapter 4 illustrates one of the many potential benefits of having more spatially accurate crash data.

1.4 Thesis Organization

This thesis is organized into six chapters. Chapter 2 provides a review of relevant literature and the use of crash database in different states. Chapter 3 evaluates crash geocoding in South Carolina using GPS technology and the new SCCATTS (South Carolina Collision and Ticket Tracking System) system. Chapter 4 describes the analysis and comparison of crash database in South Carolina in different years. Chapter 5 gives conclusions and provides recommendations based on the results of the research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Evolution of Crash Geocoding and Reporting

Over the previous two decades, numerous states in the U.S. have made advancements in crash reporting to improve safety data. Improvements have included: use of barcode scanners to ensure connection between drivers involved in crashes and their driving records, use of global positioning systems to pinpoint the location of crashes in the roadway network, and use of laptops and other devices to collect standard crash data, among others. From an infrastructure standpoint, systems developed to improve crash location characteristics are inherently important because without a spatial context for the crash problem, it is much more difficult to identify the source of causation factors and hence appropriate countermeasures including where improvements should be implemented to have the greatest potential impact (*Havlicek et al.*).

For many decades, DOTs have defined the location of a crash using route identifiers along with distances to reference points (e.g., route ID and directional distance to intersection, route and mile point and; route and distance from some reference post). While these methods may appear appropriate, there are a number of problems associated with route identifiers and distance measurements in the field where police officers must obtain data measurements. Route identifiers are problematic because there is not always a single universal identifier used by all agencies within the same state. Often times a road has multiple route designations such as the section of interstate going through downtown Atlanta, Georgia which is part of I-85 and I-75. Furthermore, some secondary roadways have multiple names and numbers, and may change names over time. Distance measurements are similarly difficult. With respect to measurement estimates determined in the field, most people do not have a good judgment for how far away an object is and officers may not have the proper equipment, or time, to actually measure the distance. In many instances, locations are estimated using rounded values such as a quarter mile. This results in clusters of crashes that really do not occur in close proximity to each other *(Sarasua et al., 2008)*. Additionally, when measurements are based off reference points or crossing streets, the notation becomes complex and the location may be misconstrued. Due to drawbacks and inaccuracies associated with these methods, many states have added coordinate locations using Global Positioning System (GPS) technology, Geographic Information System (GIS) platforms or a combination of both for safety data management and analysis because of the many advantages coordinate based methods have over the traditional location referencing methods. Some of these benefits are increased crash data spatial accuracy and reduced post-processing of location information to facilitate mapping.

By the mid-2000s, states such as Iowa, Illinois, Kentucky and Massachusetts had developed and widely deployed, electronic crash data collection systems to be used by law enforcement officers *(Cherry et al., 2006).* Iowa's Traffic and Criminal Software (TraCS) consists of bar code scanners, swipe-card readers, digital cameras, GPS technology, a GIS viewer and touch pads to aid digital data entry *(Cherry et al., 2006).* As of 2007, TraCS had been adopted in 18 states and 2 Canadian provinces *(Smith et al., 2005).* More recently, Alabama combined an electronic citation (E-Citation) application and the states' crash database analysis software called Critical Analysis and Reporting Environment (CARE) to create a GIS platform where police officers could map vehicle crash and traffic citation locations *(Smith et al., 2005)*. Other states including Louisiana and Tennessee have also recently adopted similar systems and have reported improvement in the quality of their crash data, from a collection standpoint *(FHWA, Peer-to-Peer Program, 2011)*. Wisconsin Department of Transportation (WisDOT) and South Dakota State University developed a Crash-Mapping Automation Tool (C-MAT) which consist of Java, Oracle and ArcGIS programming languages and has been thoroughly evaluated in terms of accuracy, precision and completeness. *(Qin et al., 2013)*

2.2 Use of GIS to Facilitate Crash Analysis

GIS conveys a spatial dimension to crash data, which helps analysts to understand the crash in context of the roadway and environment. Having spatially accurate crash data can improve understanding of the factors involved in the incident and can help identify the most appropriate countermeasures *(Miller 1999).*

GIS visualization techniques are useful in crash data analysis. There have been numerous studies that have made use of GIS to facilitate crash analysis. The analysis of Observed Relative Crash Risk done by Li and Zhang used three dimensional GIS tools to represent areas where multiple crashes occur in close proximity. Figure 2.1 shows roadway segments as columns where the height of the column gives an indication of crash risk

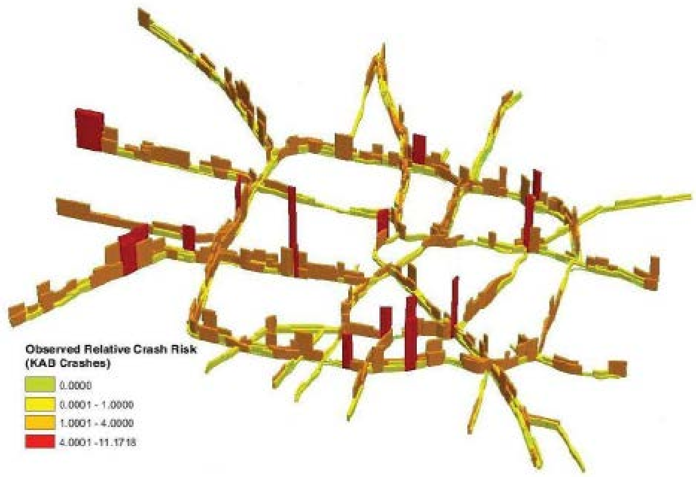


Figure 2.1: Segments Shown As 3-D Columns to Show Crash Risk and Grouping (*Li and Zhang 2007*)

Anekar, et al performed a Kernel Density analysis on pole related crashes in South Carolina using the spatial analyst toolbox in Arcview GIS. Their analysis identified major hubs of pole crashes in particular areas throughout the state (*Anekar 2010*). Figure 2.2 shows the resulting density of pole crashes in South Carolina.

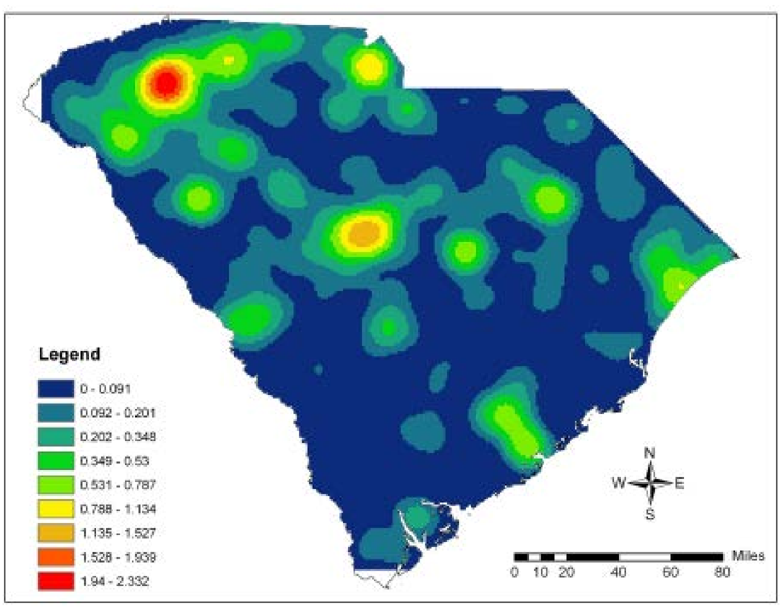


Figure 2.2: Kernel Density Analysis on Pole Crashes in South Carolina

Several states are currently using GIS to perform cluster and hotspot analyses. MassDOT is using their crash location data for developing safety improvement projects. The top High Crash Location Report is one of the tools used in their process (Figure 2.3). Using the crash data from 2010-2012 MassDOT developed a report type where high intersection locations included top high crash intersection location and also the weighted highest frequency bicycle-motor vehicle and pedestrian-motor vehicle locations *(2012 Top Crash Location Report, MassDOT).*

Using GIS tools, the MassDOT Highway Division is able to categorize locations that are qualified for Highway Safety Improvement Program (HSIP) funding. An HSIP qualified location is a crash cluster that ranks within the Top 5% of each Regional Planning Agency *(2012 Top Crash Location Report, MassDOT).*

While the MassDOT's GIS system is state of the art, the types of cluster analysis that they are currently conducting do not require precise crash location data. The clusters are identified using buffers that actually buffer a significant distance from a crash when defining the clusters as shown in Figures 2.4 and 2.5.

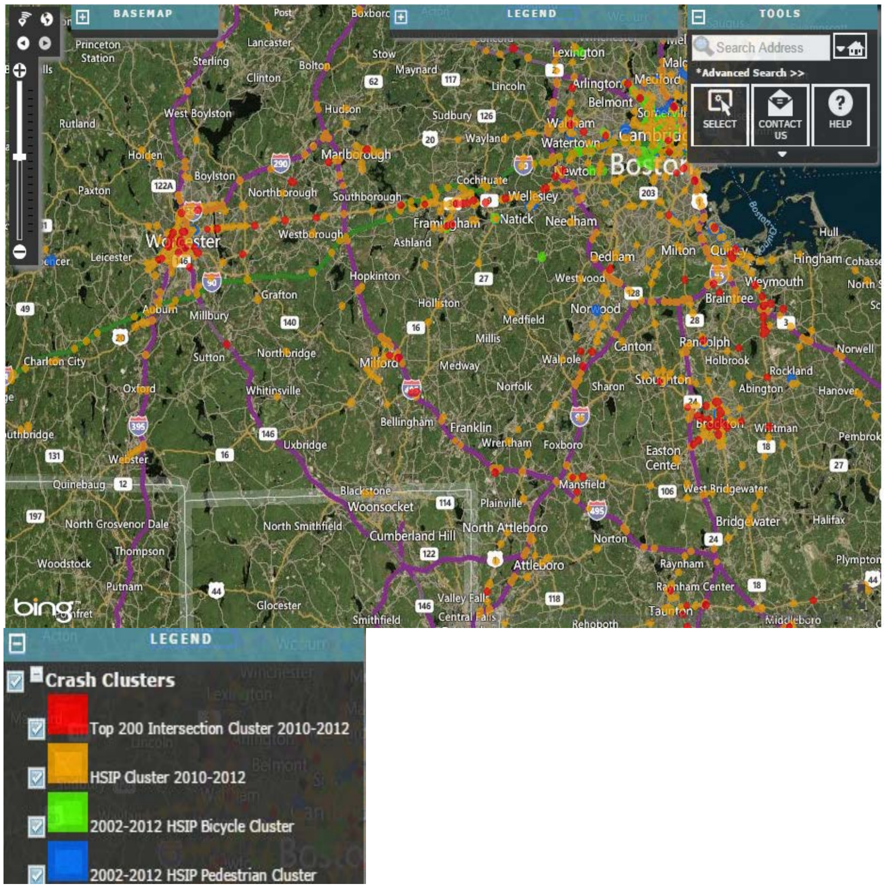


Figure 2.3: MassDOT Interactive Crash Cluster Map (From MassDOT official Website)

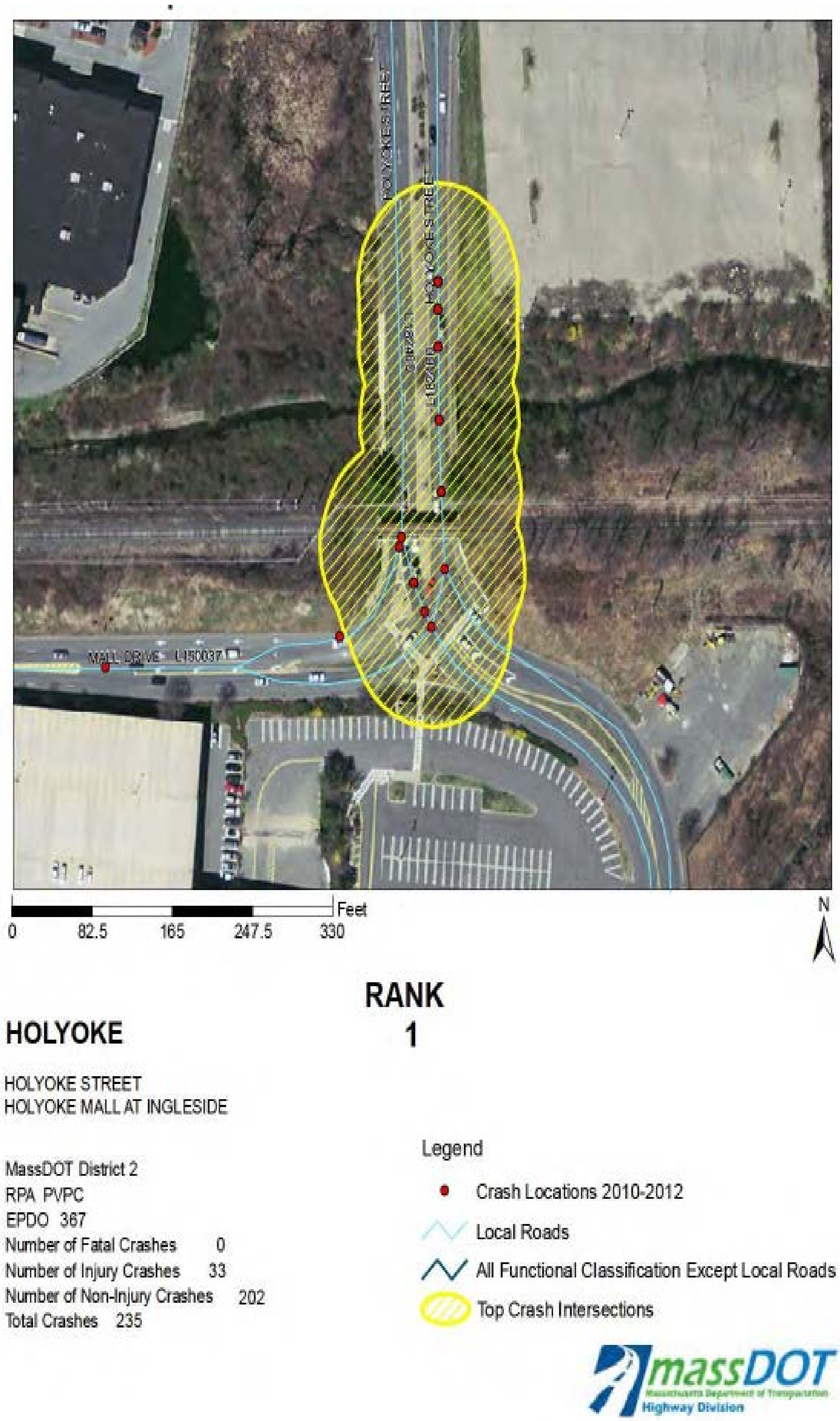


Figure 2.4: Top Crash Intersections 2010-2012(From MassDOT official Website)

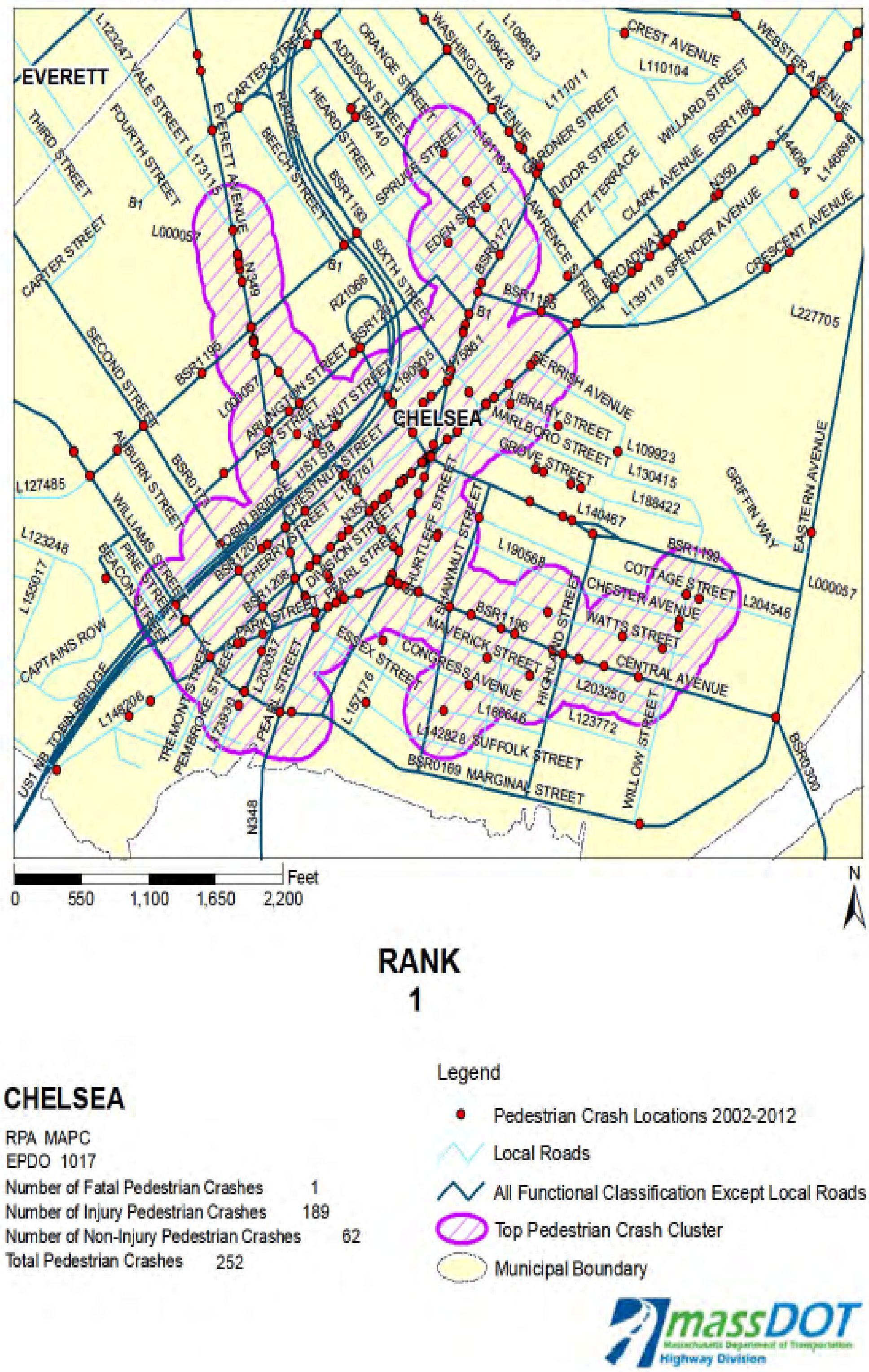


Figure 2.5: Top Pedestrian Crash Clusters 2010-2012(From MassDOT official Website)

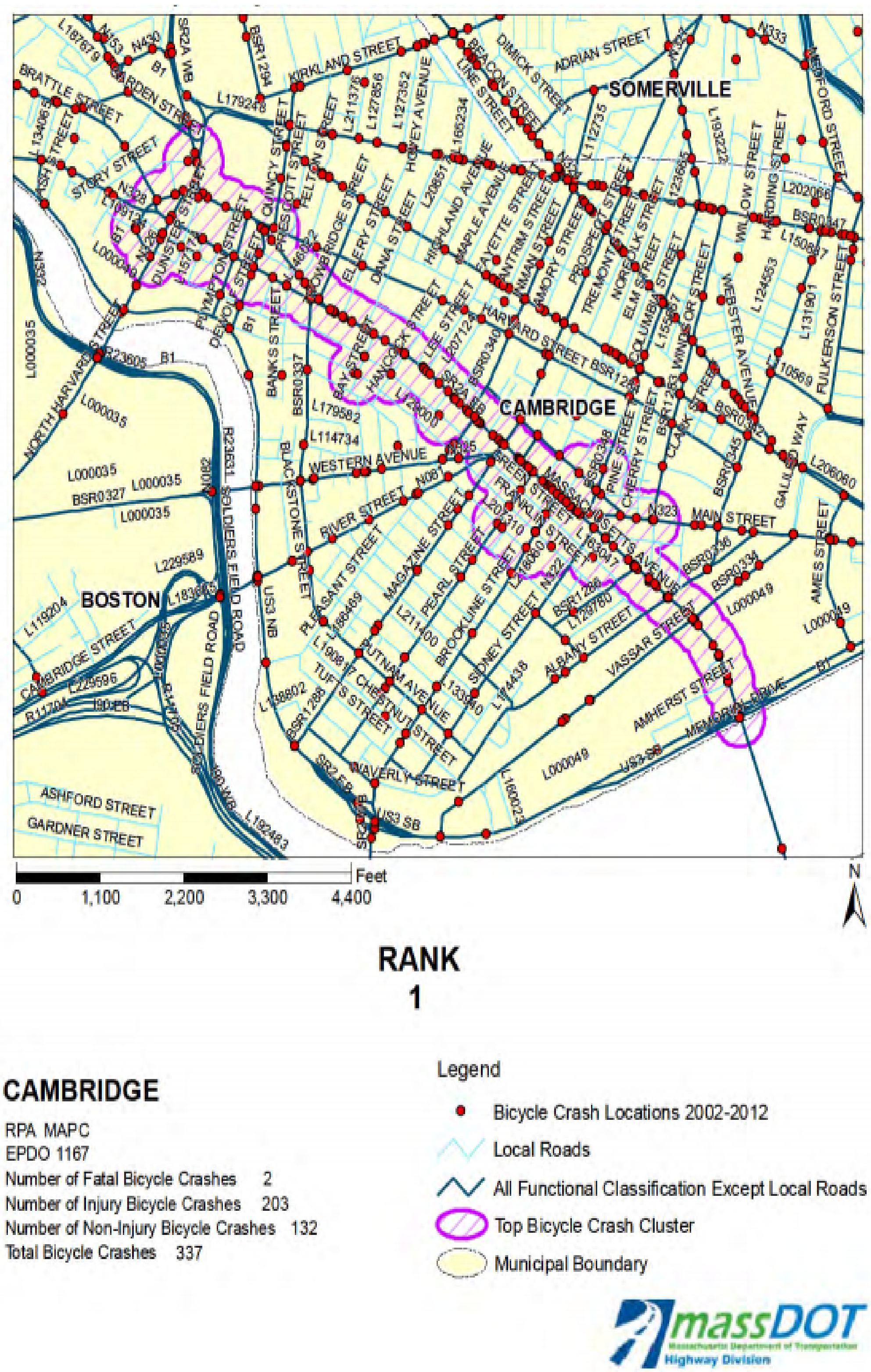


Figure 2.6: Top Bicycle Crash Clusters 2010-2012(From MassDOT official Website)

Another Vehicular Crash Analysis done by McNeil et. al used GIS tools to identify problem areas and potential causes within Washington County, Oregon. A kernel density analysis was done using 650 foot kernel and one mile search radius. This test was performed on all crashes in the county and mapped against block group population density. This disclosed clustering of crashes in areas of denser population as shown in the Figure 2.7 below:

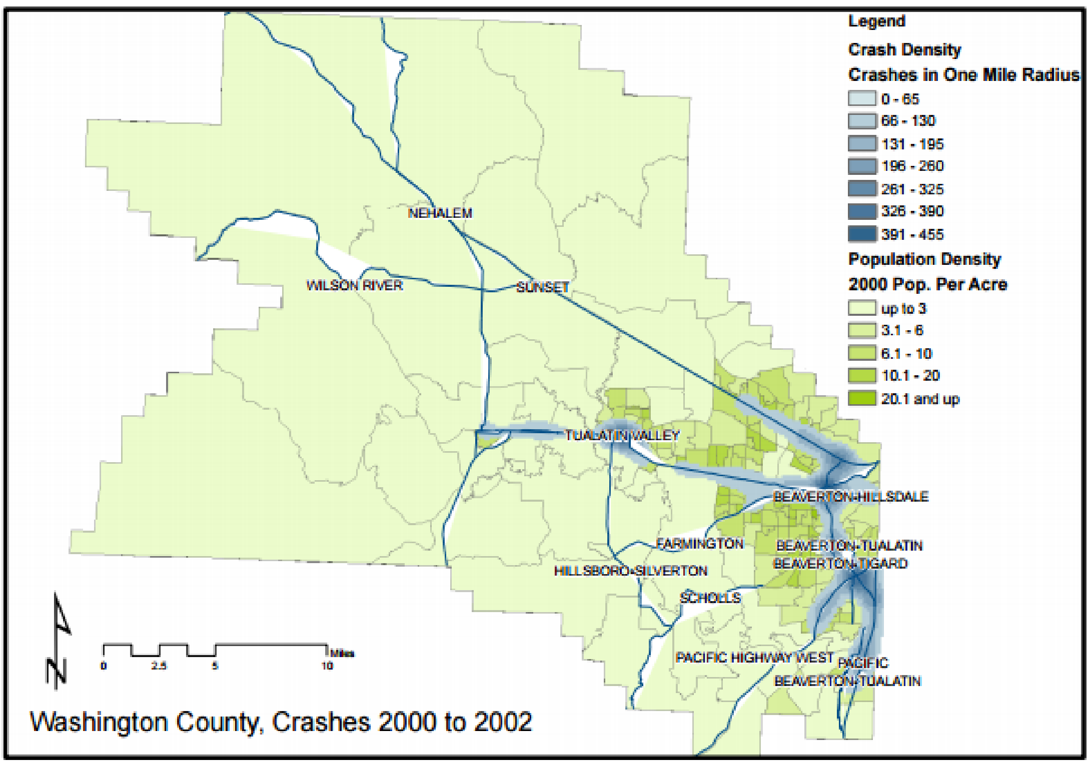


Figure 2.7: Crash Density and Population Density, 2000-2002

2.3 Crash Reporting in South Carolina

The transition to use of GPS technology in crash data collection in South Carolina began in 2004 when the SCDOT purchased hand-held GPS units for law enforcement officers to collect coordinate (latitude, longitude) information for crash reports. The use of GPS was not automated. An officer would read the coordinates display in the GPS and then write them on the paper crash report. Information from the paper report would later be keyed into a digital database. Although use of GPS units was advantageous over traditional location referencing methods, there were a number of issues associated with operation of the units and the recording of location data on paper crash reports (*Sarasua et al., 2008*).

The initiative to improve the quality of collected crash data in South Carolina has been a coordinated multi-agency effort led by the Traffic Records Coordinating Committee (TRCC). Agencies involved in the TRCC are SCDPS, SCDOT, South Carolina Department of Motor Vehicles (SCDMV), South Carolina Judicial Department (SCJD) and South Carolina Department of Health and Environmental Control (SCDHEC) *(Stantec and CDM Smith, 2013)*. In 2008, TRCC undertook a major project to improve crash data quality through implementation of an automated crash data collection system called the South Carolina Collision and Ticket Tracking System (SCCATTS) to be used by law enforcement *(Stantec and CDM Smith, 2013)*. This system enables officers to spatially see and locate crashes via a GIS-based GPS enabled mapping platform in the police vehicle. The GPS would display the vehicle's location on the GIS map display and then the officer has the ability to pinpoint the actual location of the crash rather than where the officer's vehicle is (e.g. on the side of the road or in a parking lot, etc). The officer can key in all other information related to the crash which is later uploaded to the SCDOT database. The implementation of this automated system was spearheaded by SCDPS and SCDOT. The deployment of the system began in 2010 and as of April 2013, all highway patrol vehicles and 20 of over 200 local law enforcement agencies have been equipped with SCCATTS *(Stantec and CDM Smith, 2013).*

2.4 Chapter Conclusion

The proliferation of GPS technology has caused many DOTs to move to a coordinate based system to geocode crashes. The combination of GPS and GIS has now become the state of the art for crash reporting as many states have adopted such a system including the South Carolina Highway Patrol as well as several South Carolina local jurisdictions.

The analysis of crash data using GIS has been conducted for more than two decades however most of these studies do not require precise crash location data. Hotspot, cluster, and many other types of analyses typically focus on the proximity of crashes rather than a precise location. Very little literature could be found where precise crash location data was vital for GIS analysis. One possible reason for this is that GIS-based crash location data has historically been relatively imprecise compared to what is now available in many states including South Carolina.

A great deal of analyses requiring precise crash locations is done by creating collision diagrams from actual crash reports. While effective for identifying troublesome turn bays, two-way left-turn lanes, or driveways, this process is labor intensive and is usually conducted for a small sample of locations that experience a significant number of crashes annually. Using the crash reports, countermeasures can be identified to alleviate specific safety issues. A potential benefit of precise crash geocoding is that collision diagrams could potentially be generated much more efficiently minimizing the need to refer to individual crash reports.

CHAPTER THREE

SOUTH CAROLINA CRASH DATA EVALUATION AND GEOCODING

Over the past decade, the aforementioned two major SCDOT initiatives (GPS and SCCATTS) have proven to be effective in improving crash data locations. This section compares and contrasts the accuracy of the crash location data recorded with the hand-held GPS units from 2004 to 2010 and use of the GIS-based map location system from 2011. This comparison was based on geocoding 9 years (2004 – 2012) of South Carolina crash data. Over 1,000,000 crashes were analyzed during the geocoding process. The crash data location files were first converted from a text file format into Microsoft Access databases and Excel spreadsheets to make it easier to analyze and geocode the crash data.

Considerable effort was undertaken in 2007 to review the accuracy from implementation of hand-held GPS units on crash location accuracy. Assuming law enforcement officers collected the crash data using latitude and longitude in Degrees-Minutes-Decimal Seconds (DMS) as instructed, the team first geocoded the 2004 crash location dataset as received from SCDOT in ArcGIS as a baseline test of the quality of the crash data. Results of the geocoding are presented in Figure 3.1(a) for all jurisdictions. The figure shows obvious location problems because as evidenced by the large number of crashes geocoded outside of the state boundary. Figure 3.1 (b) shows the results of 2012 geocoded highway patrol crash data for comparison. A review of the data for all 9 years resulted in the identification of several systematic errors and erroneous inputs that were consistent with findings from a previous study by Sarasua et al. Common problems in the crash database include:

1. Several crash records were missing either longitude or latitude or both
2. Some crash records were in state plane coordinates, not latitude and longitude
3. Several crash records were in Decimal Degrees (DD), not DMS
4. Some crash records had their longitude and latitude values swapped
5. Most of the latitude values did not include a negative sign
6. Several coordinates were recorded with insufficient precision by one or two decimal places
7. Some crash records had spaces and letters as part of the coordinate entry
8. Some coordinates included additional zeroes to make up for the insufficient precision
9. Some crash records had erroneous coordinate values

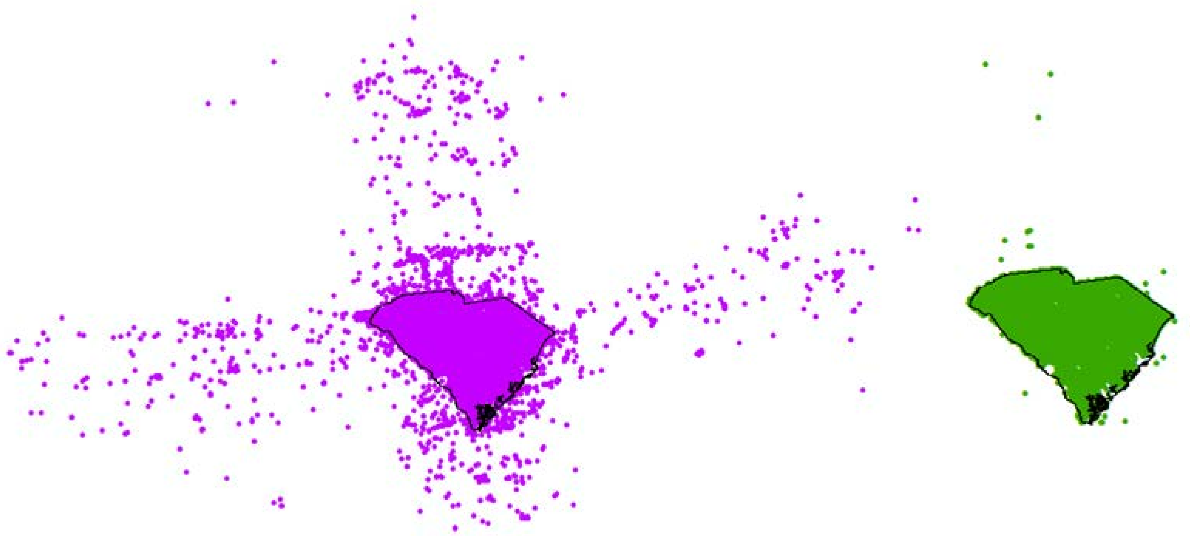


Figure 3.1: Geocoded Crashes in South Carolina: a) 2004 all; b) 2012 highway patrol

Many crash records had a combination of errors. For example, a crash record could have swapped latitude and longitude and at the same time have insufficient precision. A summary of the percentages of the geocoded data in each category by year is provided in Table 3.1. Trends from the preliminary examination of the crash data percentages shown in the Table 3.1 indicate an increase in the percentage of crash data with correctly formatted DMS latitude and longitude since 2004. The spike in the percentage geocoded in DMS latitude and Longitude in 2006 can be attributed in part to statewide implementation of the use of the hand-held GPS units that started in 2004.

Table 3.1: Percent of Crash Data by Geocoded Category and by Year

All Records (2004 – 2012)									
	Year								
Category	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
DMS	64.6	63.1	71.0	71.4	72.9	72.2	71.7	79.3	82.7
DD	7.7	11.3	11.0	8.1	6.6	5. 8	6.1	0.0	0.0
State Plane	2.5	2.7	2.9	2.7	2.8	2.8	2.9	0.4	0.2
No Lat/Lon	12.0	11.9	10.9	12.1	12.4	12.0	13.4	19.6	16.6
Other	13.3	11.0	4.2	5.7	5.3	7.1	5.9	0.6	0.5
Total (1000s)	110.0	113.0	111.5	112.1	117.3	106.2	107.5	117.9	121.1

Notes:

1.) DMS - degrees-minutes-seconds, DD - decimal degrees

2.) ‘Other’ category includes errors numbered 4 -9 in list of errors, provided in text.

The second spike in percentage in 2011 again coincides with substantial implementation of SCCATTS, which started in 2010. A separate analysis was conducted for crash data collected and recorded by only the highway patrol. It was clear from the data that the highway patrol received better training in the proper use of GPS than local jurisdictions. Furthermore, the highway patrol was the first adopter of the new system so they represent the best case scenario for geocoding accuracy. Table 3.2 provides a summary for the data collected by the highway patrol for years 2004-2012.

Table 3.2: Percent of Highway Patrol Crash Data Format Categories by Year

Highway Patrol (2004 – 2012)									
	Year								
Category	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
DMS	88.0	90.2	92.4	95.6	97.2	96.4	96.6	99.4	99.8
DD	6.2	5.4	6.1	2.9	1.7	1.8	1.8	0.0	0.0
State Plane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
No Lat/Lon	0.9	1.3	0.1	0.0	0.0	0.0	0.1	0.4	0.0
Other	4.8	3.1	1.4	1.5	1.2	1.7	1.5	0.2	0.2
Total HP (1000s)	61.3	60.5	60.7	61.2	58.9	59.3	59.1	72.9	76.0
Total Crashes (1000s)	110.0	113.0	111.5	112.1	117.3	106.2	107.5	117.9	121.1
HP % of Total	55.8	53.5	54.5	54.6	54.9	55.9	55.0	62.8	62.8

Notes: 1.) DMS - degrees-minutes-seconds, DD - decimal degrees

2.) 'Other' category includes errors numbered 4 -9 in list of errors, provided in text.

In evaluating crash data recorded by only highway patrol, it is evident the majority of issues and systematic errors result from crash data recorded by local jurisdictions other than highway patrol (i.e., city and county police departments). Similar to trends for all crash data for the state, the percentage of highway patrol recorded crash data with correctly formatted latitude and longitude gradually increased over the years. The spikes in percentages again coincide with the change and statewide implementation of both hand-held GPS units and SCCATTS. Unfortunately, crash data collected by the highway patrol and the few jurisdictions that use the new system, only account for roughly 60% of crash data records as of 2013 *(Stantec and CDM Smith, 2013)*.

Aside from issues and errors outlined from the initial examination of geocoding potential of crash location data, there was also the issue of accuracy – or proximity of the crash coordinates to their actual location. For example, one analysis of data showed that many crashes whose coordinates fell within the state, however, were identified as occurring outside the reported county boundary. Recorded crash data by the highway patrol with correctly formatted latitude and longitude values were used for this analysis. The highway patrol data from 2007 to 2012 was geocoded and crashes were later joined spatially with the counties they fell in after the geocoding. Crashes that had conflicting county IDs from the crash database and the GIS county layer were identified and corresponding findings are summarized in Table 3.3.

Table 3.3: Percent of Highway Patrol Crashes in Wrong County

Highway Patrol (2007 - 2012)						
	Year					
Category	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
DMS	95.6	97.2	96.4	96.6	99.4	99.8
Wrong County	3.6	3.8	4.1	3.9	2.2	1.9

Table 3.3 shows a gradual increase in the percentage of crashes located in the wrong county from 2007 to 2009, and a decreasing pattern from 2010 to 2012. This latter decreasing pattern is an indication of the changes in the crash data collection methods from hand-held GPS units to GIS-based map equipped with GPS.

3.1 Chapter Conclusion

This chapter has shown that there has been a vast improvement in the geocoding of crash data in South Carolina. The new SCCATTS system has virtually eliminated the systematic errors that were associated with transcribing coordinates from handheld GPSs. In the next chapter, we will look at how SCCATTS has improved the precision of crash locations and how this improvement can benefit safety analysis.

CHAPTER FOUR

ANALYSIS

4.1 GIS Analysis of South Carolina Crash Data

Additional spatial analysis that focused on the accuracy of geocoded crash data was conducted to further evaluate the improved spatial accuracy of geocoded crash data using SCCATTS. Three years (2010-2012) of crash data, with systematic and random errors removed, was geocoded. The highest ranking corridors from a crash standpoint were the focus of this study. The majority of 2010 crash data was collected by highway patrol officers using a hand-held GPS unit while 2011 and 2012 data were collected using GIS-based map equipped with GPS (SCCATTS). An indication of the difference in precision of the two methods can be seen in Figure 4.1. The US-25 corridor example in Figure 4.1 shows that while 2010 crashes are mostly located on the sides of the roadway, or in parking lots, most of the 2011 crashes are shown on the roadway and in the location most likely to be where the crash actually occurred. A probably explanation for why 2010 data were mostly off the roadway is that most police officers would park their vehicles on the side of the roadway, or in parking lots, when filling out parts of the crash report and would read and record GPS coordinates on the GPS unit wherever they were parked.

The 2011 and 2012 data collection using the GPS enabled GIS-based map provided the police officers the tools to identify approximate crash location using GPS, and then accurately locate (or pin) the crash at the precise location it occurred on the map, even when parked on the side of the road, or in a parking lot.

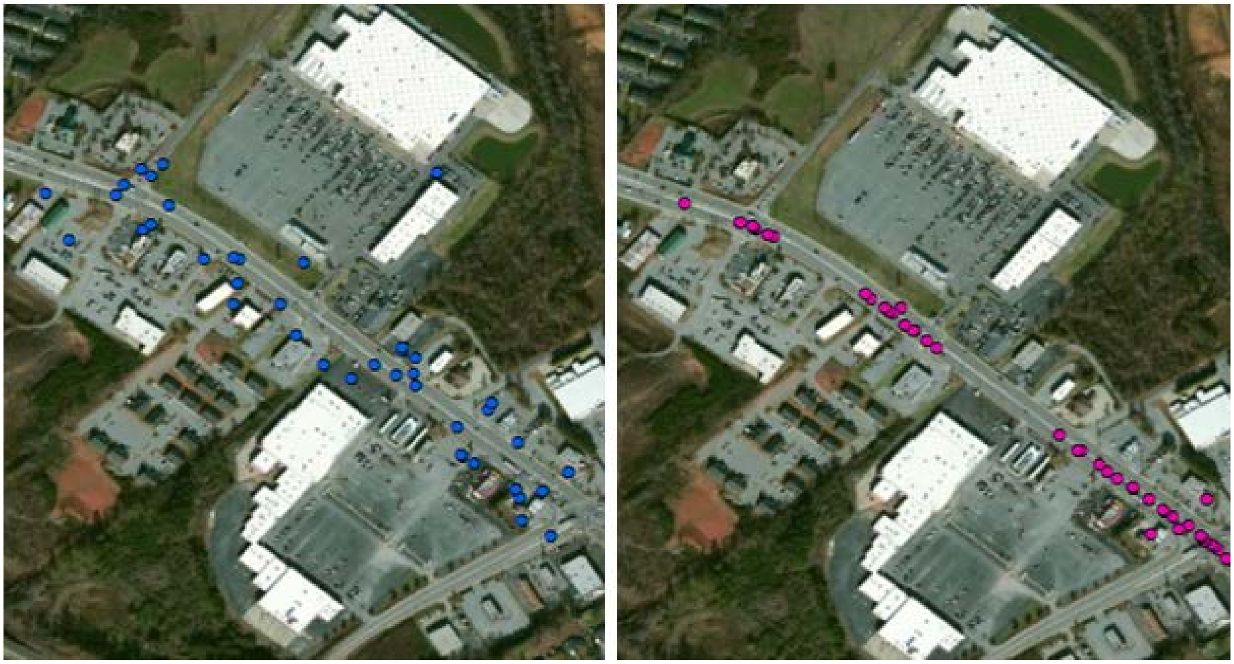


Figure 4.1: Rear-End and Angle Crashes on US 25 in Greenville, SC for 2010 (Left) and 2012 (Right)

4.2 Proximity Analysis

A proximity analysis was conducted to determine if there was a change in crash location relative to a roadway's centerline before and after the implementation of the SCCATTS. The distance of each crash to its reported corridor was calculated and averaged by corridor using spatial analysis tools in ArcGIS for the 3 years. Table 4.1 shows the results the proximity analysis for the top 5 selected corridors based on average crash rank.

Table 4.1: Average Distance from Reported Route by Year

Route	Ave Distance (FT)		
	2010	2011	2012

US1 Richland	14.6	3.7	3.2
US25 Greenville	17.8	2.4	1.3
SC146 Greenville	18.6	1.8	1.0
US176 Richland	15.3	1.7	1.1
US1 Lexington	14.7	4.4	4.7
SC9 Spartanburg	14.9	3.1	2.9
US17 Berkeley	16.3	4.2	3.9
US17 Horry	15.1	3.2	2.6
US21 York	12.3	3.5	3.3
US29 Greenville	15.6	1.8	1.6
US52 Florence	16.9	2.8	2.3

As expected, Table 4.1 shows 2010 crashes were further away from their reported route centerline than the 2011 and 2012 crashes thus clearly showing considerable change in the trend of crash locations from 2010 crashes (recorded with a hand-held GPS unit) to 2011 (recorded with SCCATTS). Paired t-tests were conducted at a 95% confidence to compare the averages and showed that the 2010 averages were significantly different from both the 2011 averages and the 2012 averages with p-value of 0.0004 and 0.0006 respectively. A comparison of the 2011 and 2012 data with a p-value of 0.08 showed that the means were statistically the same.

4.3 GIS Variable Buffer Analysis

While the proximity analysis indicates a distinct change in the average distance from centerline is evident in crash data collected after 2010, additional analysis was conducted to identify the proportion of crashes that fell within the roadway corridor's travelway before and after implementation of SCCATTS. The same corridors were used in this analysis as those identified in the centerline proximity analysis. SCDOT maintains a GIS layer of roadway centerlines for all roads on the South Carolina state route system. Attribute data is either associated with an entire centerline segment or linear referenced by mile point using dynamic segmentation. Offset lines such as lane lines, edge of pavement, and travelway limits are not included as GIS data layers. The buffer by attribute capability was used in ArcGIS to synthetically generate edge of travelway polygons for all five corridors. Typical GIS buffer operations use a fixed offset distance for all selected segments to be buffered. Buffering using buffer by attribute creates a polygon based on an attribute of individual segments, which in this application, buffered the roadway centerline segments using the buffer distance as half of the travelway width attribute value as identified in the South Carolina Roadway Inventory Management System (RIMS) database. For the most part, the resulting travelway buffer followed the underlying aerial imagery very well however, there were some problems. In some cases, the GIS roadway centerline did not follow the actual centerline causing the buffer to be offset in places. The other problem is that the RIMS travelway width attribute for some segments is coded incorrectly. Figure 4.2 provides examples of buffered travelway that included errors (left) along with corrections (right).

Using a GIS point-on-polygon spatial aggregation, the crash data is overlayed with the travelway buffer polygons to identify crashes that are geocoded within the travelway corridors. Table 4.2 shows the results of this analysis. It shows that only 27 to 48 percent of the 2010 crashes fall within the travelway even though it is likely that nearly all of the types of crashes used in this analysis occurred in the travelway. It should be noted that fixed object and run-off-the-road crashes were omitted from the analysis. Further analysis of the sections of the routes listed in Table 4.2 reveals that 2010 crash percentages do not represent the potential conflict points, which should all be on the travelway. However, 2011 and 2012 crash data realistically represent potential conflicts on the travelway. In 2012, over 95% of the crashes occur within the travelway buffer where actual conflict points exist.

Table 4.2: Percent of Highway Patrol Crash Data Identified by Corridor by Year

		2010 Crashes			**2011 Crashes**			**2012 Crashes**		
Route	Miles	HP	In TW	In TW%	HP	In TW	In TW%	HP	In TW	In TW%
US1 Richland	18.3	620	411	66.3	726	712	98.1	681	679	99.8
US25 Greenville	18.7	755	404	53.5	833	649	80.1	836	692	82.8
SC146 Greenville	11.7	372	201	54.0	506	489	96.6	550	545	98.9
US176 Richland	14.1	413	258	62.5	445	420	94.4	533	513	96.2
US1 Lexington	17.7	384	233	60.7	419	381	94.2	436	388	89.1
SC9 Spartanburg	15.6	300	167	55.7	344	325	94.5	363	345	95.0
US 17 Berkeley	18.7	335	147	43.9	337	267	79.2	370	325	87.8
US21 York	35.6	151	115	76.2	201	191	95.0	195	185	94.9
US52 Florence	20.3	192	118	61.5	250	212	84.8	123	88	71.5
US17 Horry	55.4	737	455	61.8	815	724	88.8	784	706	90.1

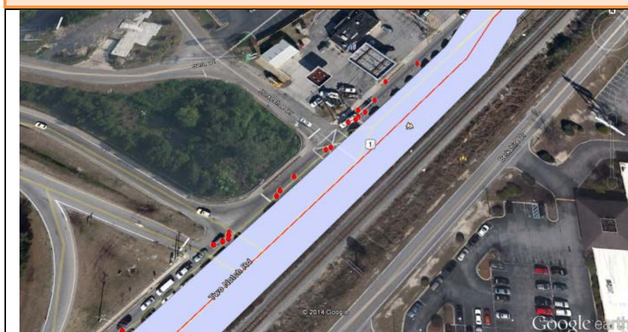
US29 Greenville	15.4	282	202	71.6	308	297	96.4	349	349	100

Notes:

1.) HP – SC Highway Patrol

2.) In TW – Number of crashes located by GPS within defined corridor travelway

3.) In TW% – Number of crashes located by GPS within defined corridor travelway as percentage of total known corridor crashes, based on SC HP crash records



US 1 Richland, centerline location problem

US 1 Richland, centerline location GIS correction

US 1 Richland, travelway width problem

US 1 Richland, travelway buffer correction

Figure 4.2: Results of the GIS Travelway Buffer Operation Including Corrections

4.4 Analysis of Driveway Related Crash Data

Further spatial analysis focusing on the accuracy of geocoded driveway crash data was performed as part of an ongoing study by Clemson University for the South Carolina

Department of Transportation (SCDOT). This study involves analysis of crash data to support development and implementation of improved access management policies in South Carolina, through demonstration of the benefits from use of precise crash location data in access management program evaluation. Three years (2010-2012) of geocoded crash data was used for this analysis, with systematic and random errors removed. Crashes that were potentially driveway related (i.e. coded with junction type –'driveway' or coded with a 'manner of collision' of 'rear-end' or 'angle' or 'side-swipe' or 'head-on') were extracted for use in this study. The average crash rank of corridors based on total driveway related crashes over the 3 years were used to select corridors with the highest likelihood of access management issues from a safety perspective.

Reliable crash data that provide accurate crash locations is essential for safe access management practices *(Chowdhury et al., 2008).* The improved spatial accuracy of crashes makes it possible to pinpoint the locations where clusters of crashes occur in relation to a driveway. This is evident at the location shown in Figure 4.3 on US 1 in Columbia, South Carolina. The Figure 4.3 shows a number of driveway related crashes (shown with stars) occurring when vehicles attempt to enter or exit from adjacent fast-food restaurants across a left-turn bay. The accuracy of crash data prior to 2010 would not produce evidence of these clusters making it difficult to identify where crashes occur relative to driveways unless the sketches made by officers on the original crash reports are analyzed individually.

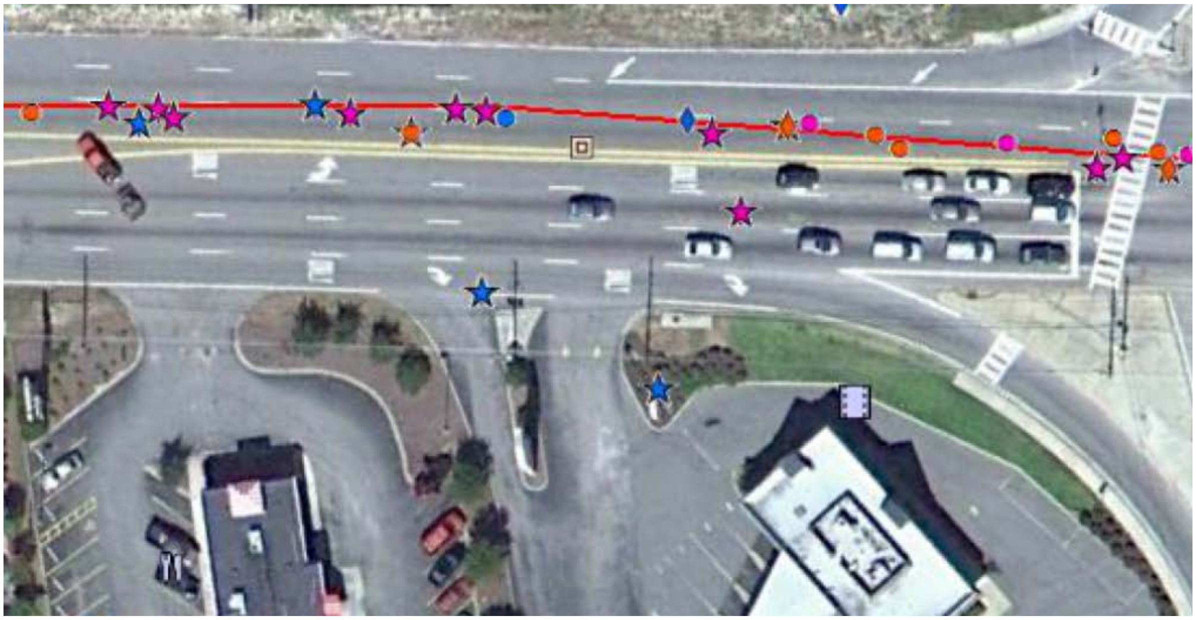


Figure 4.3: Driveway Related Crashes Over a Three Year Period on US Highway 1 in Richland County, SC

* Coded driveway related crashes shown with stars. Note the proximity of the crashes relative to the left-turn bay (image from Google Earth)

To determine the effects of the characteristics of driveways on crash incidence, it is necessary to associate driveway crashes with driveways. This presents two very difficult problems that must be overcome. First, it is necessary to distinguish driveway crashes from other crashes; and second is to develop a one to one association of a driveway crash to a particular driveway. Only then is it possible to determine driveway crash rates.

4.4.1 Issues with Junction Type

For the first problem it would be ideal if just use “junction type=driveway” could be used indicated in crash reports however an analysis of the crash data indicates that many obvious driveway related crashes would be omitted. Many crashes occur within close proximity to driveways or in the two way left turn lane (TWLTL) that, in most cases, are likely driveway related. A study of midblock crashes along selected corridors that occur in TWLTLs not near intersections showed that less than 25% were coded as "junction type=driveway". Figure 4.4 demonstrates several crashes that were coded as "junction type=no junction" It is apparent from this analysis that only using crashes coded as driveway crashes will underestimate the crash incidence related to access management policies. Thus, the research only eliminated crash types that were unlikely to be driveway related such as fixed object crashes and run-off-road crashes.

Figure 4.4: Driveway Related Crashes Coded as "No Junction"

Table 4.3 shows that roughly 25% of highway patrol crashes that fell within driveway buffers along the sample of corridors are actually coded driveway crashes in the crash report. Another 25% of those crashes falling within driveway buffers are considered occurring at some sort of intersection (4-way intersection, T-intersection, Y-intersection, etc.). Note that only segment crashes were used in this analysis – all crashes in the intersection influence areas were removed. Finally, the majority of the crashes falling within the driveway buffers were considered ‘no junction’ by the highway patrol which is demonstrated in table 4.4.

Table 4.3: Junction Type Coding for Crashes within Driveway Buffers

Junction Type Codes	Frequency	Percent
0-Blank	53	3.1%
1 -Crossover	10	0.6%
2- Driveway	435	25.8%
4 - 4way Intersection	164	9.7%
5 - Railway Grade Crossing	3	0.2%
8 - T Intersection	268	15.9%
12 - Y Intersection	5	0.3%
13 - No Junction	749	44.4%
99 - Unknown	1	0.1%
	1688	

Table 4.4: Percent of driveway Related Midblock Crashes coded as "intersection" crashes

CORRIDOR	SC9 SPARTANBURG	SC146 GREENVILLE	US1 LEXINGTON	US1 RICHLAND	US17 BERKELEY	US17 HORRY	US21 YORK	US25 GREENVILLE	US 29 GREENVILLE	US52 FLORENCE	US176 RICHLAND
HP 2012	42/208 (20.2%)	50/371 (13.5%)	16/245 (6.5%)	16/308 (5.2%)	48/235 (20.4%)	37/227 (16.3%)	9/116 (7.7%)	72/437 (16.5%)	15/164 (9.1%)	11/77 (14.3%)	140/378 (37%)
2012 ALL CRASHES	42/208 (20.2%)	57/409 (13.9%)	32/325 (9.8%)	17/312 (5.4%)	52/288 (18.1%)	55/335 (16.4%)	48/284 (16.9%)	72/437 (16.5%)	27/197 (13.7%)	32/163 (19.6%)	144/391 (36%)
2010 ALL CRASHES	10/66 (16.6%)	15/105 (14.2%)	28/172 (16.3%)	17/143 (11.8%)	19/125 (15.2%)	24/194 (12.4%)	27/91 (29.7%)	31/158 (19.6%)	13/80 (16.2%)	44/174 (25.2%)	50/144 (34%)

4.5 Driveway Buffer Creation

After querying possible crash types that could be associated with driveways, the analysis assumption is that any crashes in an influence area of a driveway is a driveway related crash of that driveway. It is crucial that the driveway influence areas are as precise as possible in order to evaluate the driveways effectively. One approach is to use ArcGIS buffer techniques to buffer an area on the travelway adjacent to each driveway to delineate the influence area. Once these buffers are created, they can be overlayed with underlying crashes to do the association.

A more detailed analysis to identify problem driveway locations involved a study of driveway crash data within 150 feet of intersections in which the corner clearance of the driveway does not comply with published standards in the SCDOT Access Management Guidelines. As part of the Clemson access management research, a GIS database of driveways and associated driveway attributes was created for 11 corridors that were among the most dangerous in the state from a driveway crash frequency perspective. An attribute value for driveway corner clearance from an adjacent intersection was determined using aerial images. Travelway polygons from the buffer analysis were also used for this study. Travelway polygons were overlayed with 50 foot buffer polygons of a selection set of driveways that are within 150 feet of intersections.

A detailed analysis of driveway crash data within 150 feet of intersections conducted, in which the corner clearance of the driveway does not comply with published standards in the SCDOT Access Management Guidelines. The corner clearance attribute from the GIS database of driveways for 11 corridors were used for this analysis as well as a 180 foot buffer of the intersection center point. Travelway polygons from the buffer analysis were also used and were overlaid with driveway buffer polygons that were within 150 feet of intersections and fell within 180 feet of the center point of the intersection. Buffering the intersection was necessary to identify if more than one driveway falls within 180 feet intersection buffer. The intersection buffer distance of 180 feet was used to account for the width of the intersection however only driveways with an actual corner clearance of 150 feet or less were included in the analysis. The resulting polygon layers were then overlaid with the crash data to determine the number of driveway related crashes within the overlapping hatched area shown in Figure 4.5. Note that the solution is the crashes that fall within the Boolean intersection (overlay) of buffers of three different features:

1) 180 foot intersection buffer,

2) travelway buffer, and

3) 50 foot driveway buffers with a corner clearance less than 150 feet.

Table 4.5 shows the result of this analysis.

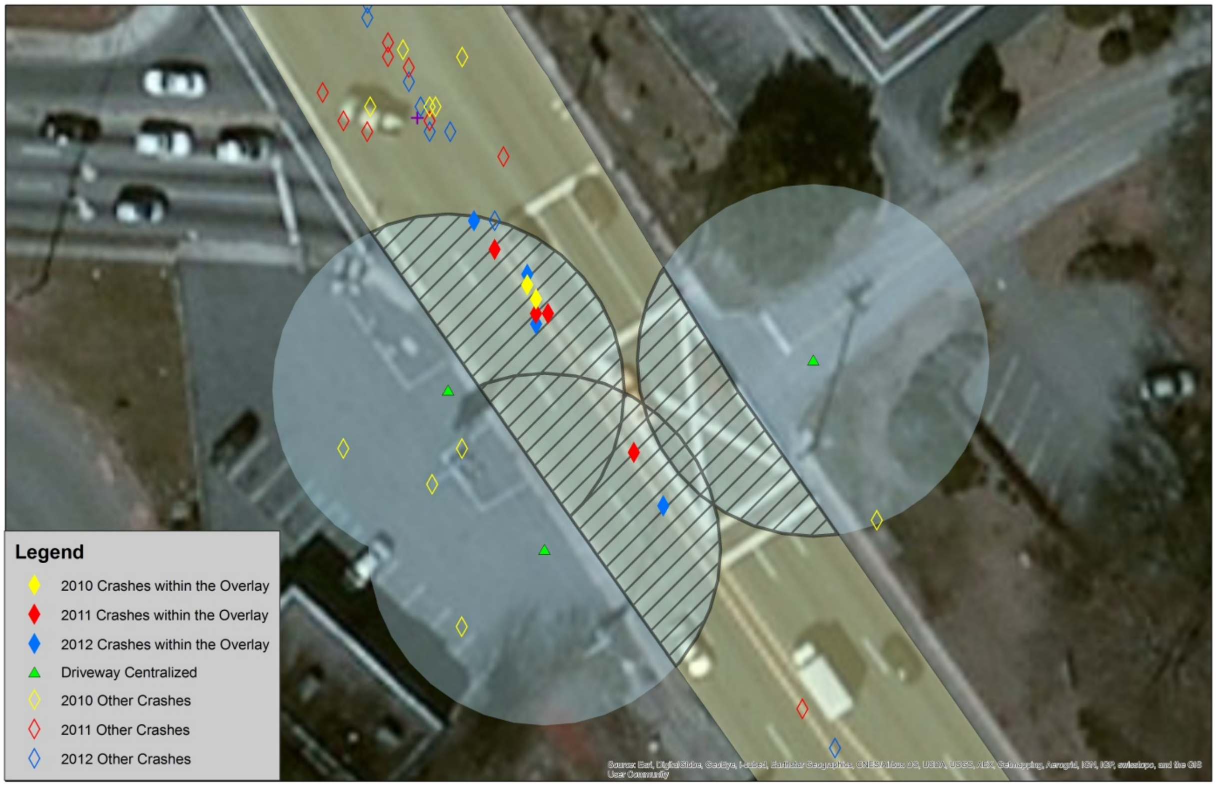


Figure 4.5: US Highway 176 in Richland County, South Carolina. Boolean Intersection Example

Table 4.5: Number of Driveway Crashes Occurring within the Hatched Area in Figure 4.5

Corridor	# of driveways	2010 Crashes	2011 Crashes	2012 Crashes
US 1 Richland	219	18	63	56
US 25 Greenville	177	9	36	51
SC 146 Greenville	29	8	18	27
US 176 Richland	102	16	30	33
US 1 Lexington	167	13	29	29
SC 9 Spartanburg	86	13	32	39
US 17 Berkeley	100	14	20	35

US 17 Horry	584	58	50	71
US 21 York	199	20	18	42
US 29 Greenville	153	6	16	24
US 52 Florence	153	29	34	37

One problem with this approach is that the resulting driveway buffers are circles around the point that represents the location of the driveway. This could bias crashes that occur closer to the side of the road. Ideally, rectangular buffers would give a better indicator of a driveway's influence area. A fellow Clemson Master's Student (Andrew Stokes) created a model that could make rectangular buffers that stretched across the roadway as part of his research *(Stokes, 2015)*. Two models were created depending on driveway type—one model for right-in right-out (RIRO) driveways (Figure 4.6) and one model for full access driveways (Figure 4.7). The driveway buffer width is the actual driveway width plus thirty feet to accommodate about a car length on each side of the driveway. The 30 foot value was identified in a separate analysis conducted by Stokes using different values starting at 0 (thus the driveway influence area would only be equal to the actual driveway width) to 60' in 6 foot increments. The number of crashes that fell within each buffer was determined and graphed. An inflection (abrupt change in slope) occurred for 30 feet *(Stokes, 2015)*.

Figure 4.6: Right In Right Out Driveway Buffers

Figure 4.7: Full Access Driveway Buffers

Figure 4.8 shows resulting driveway influence area buffers along with 2012 driveway related crash data that fall within the buffers. The analysis revealed an average crash incidence of .46 crashes per driveway for 2012. Individual driveways with a significantly higher number of crashes than the average can be identified through a simple query. The analysis showed a much lower crash incidence for the same corridors using 2010 data. The

2010 rates are deceiving because poor geocoding precision placed most of the driveway related crashes outside of the driveway buffers.

Figure 4.8: Driveway Influence Buffers Overlayed with 2012 Crashes (Image From Bing Maps)

An analysis similar the one shown in Figure 4.5 was done by using rectangular driveway buffers and the result was similar but more accurate. The resulting polygon layers dissolved using the ArcGIS tool in order to avoid the double counting and then overlayed with the driveway crash layer to determine the number of driveway related crashes within the hatched area shown in Figure 4.9. The analysis used only highway patrol data to ensure that the before data (2010 driveway related crashes) was using GPS coordinates only and the after data (2012 driveway related crashes) used the SCCATTS. The number of crashes that fell within the driveway buffer and within the street travelway buffer totaled 64 crashes in 2010, and 196 crashes in 2012. The total number of all driveway crashes did increase by about 50% however there was a 300% increase in the quantity of driveway crashes that occurred on the travelway in close proximity to intersections. While this increase is dramatic, it is clearly due, in large part, to improved crash geocoding rather than a change in actual crash incidence.   A closer look at these locations show that many of the 2010 crashes occur outside of the travelway and thus are ignored by the GIS operation.

Note that the solution is the crashes that fall within the Boolean intersection (overlay) of buffers of three different features:

1) 180 foot intersection buffer,

2) Travelway buffer, and

3) Driveway rectangular buffers with a corner clearance less than 150 feet.

Table 4.6 shows the result of the analysis.

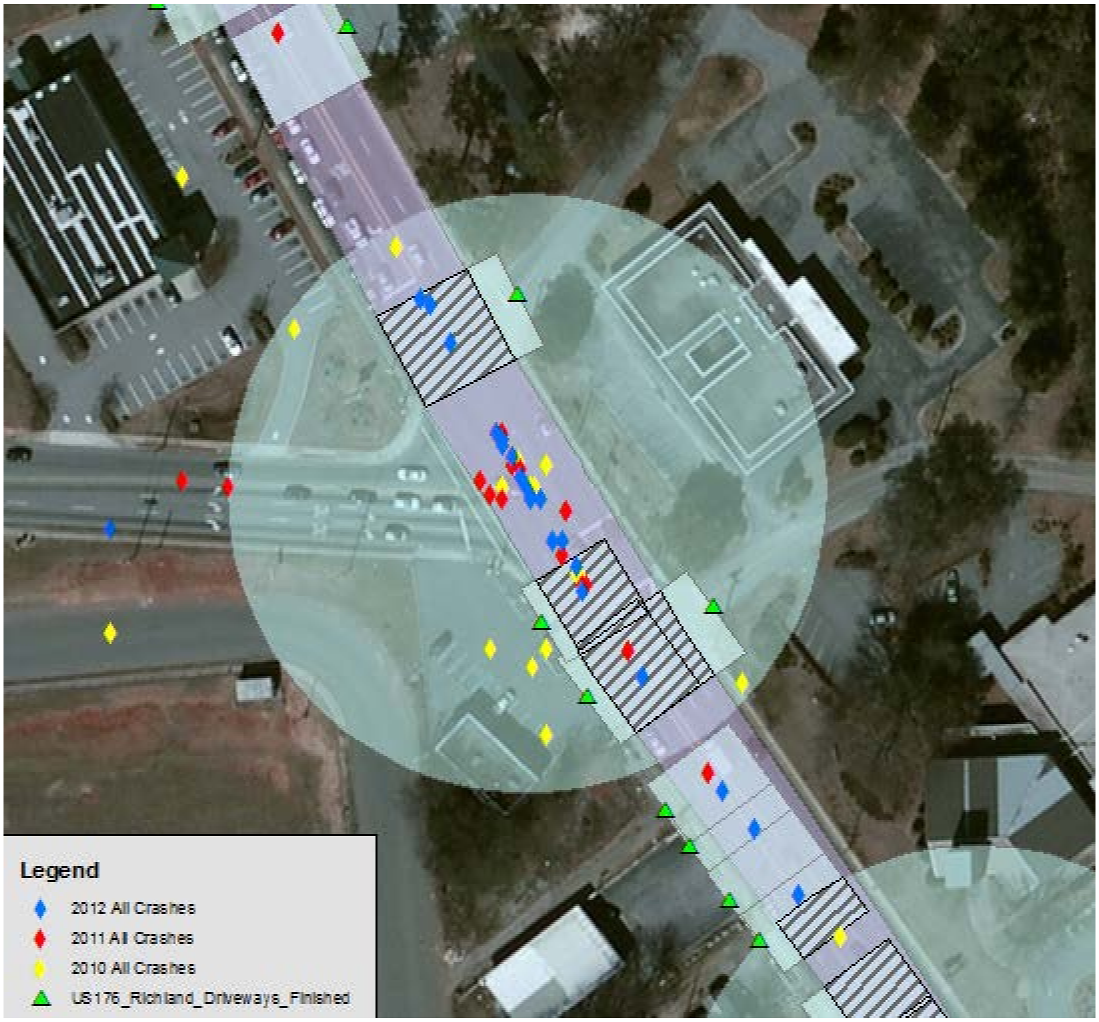


Figure 4.9: US 176 Richland Boolean Intersection Example

Table 4.6: Number of Driveway Crashes Occurring within the Hatched Area in Figure 4.9

Corridor	# of driveways	2010 Crashes	2011 Crashes	2012 Crashes
US 1 Richland	238	45	122	112
US 25 Greenville	188	24	136	169
SC 146 Greenville	53	14	51	75
US 176 Richland	117	26	69	74
US 1 Lexington	232	19	41	47

SC 9 Spartanburg	100	12	38	58
US 17 Berkeley	113	8	35	37
US 17 Horry	335	72	89	109
US 21 York	242	24	42	60
US 29 Greenville	145	13	42	52
US 52 Florence	202	35	42	47

When we compare the table 4.5 and table 4.6, there is a noticeable change in the number of crashes that are occurring within the hatched area. The reason is because most of the rectangular driveways were full access driveways and thus the rectangular buffers cover bigger areas than the 50 feet circle buffers around the driveways and thus resulted in increase of the number of crashes within the hatched area. It can be clearly seen in Figure 4.10 US 176 Richland Example.

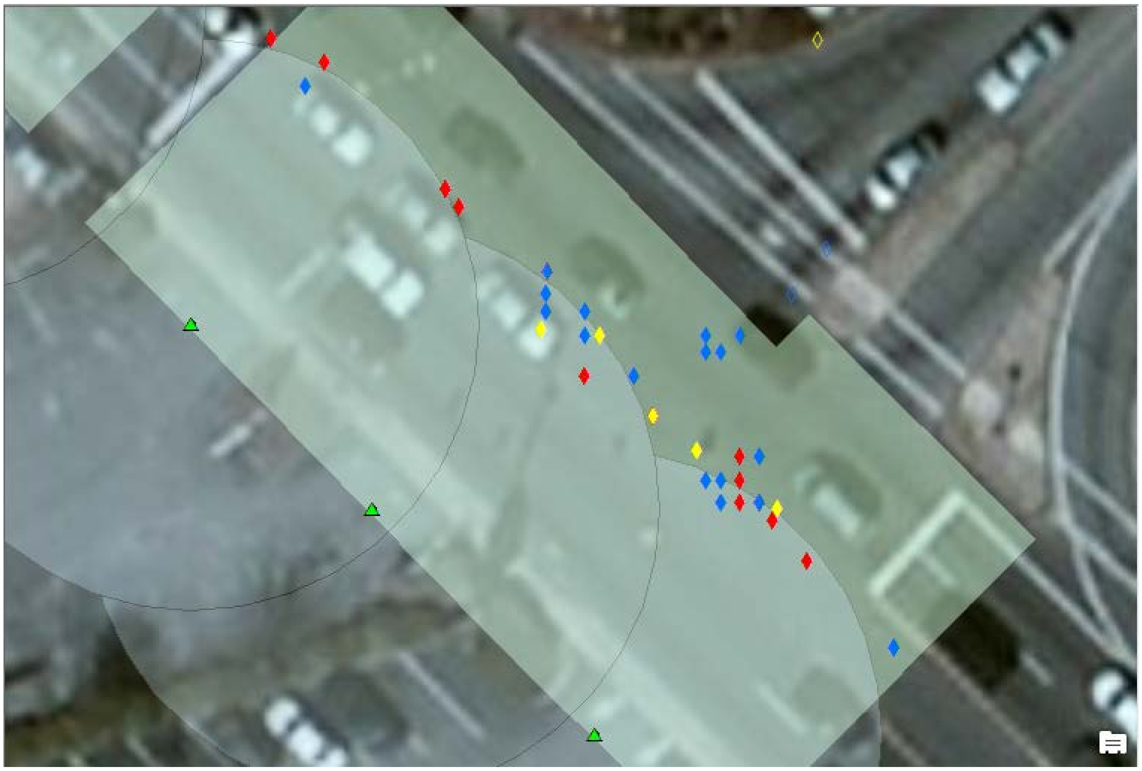


Figure 4.10: US 176 Richland Crashes Occurring Within the 50ft Circle Buffer and Rectangular Buffer.

While, the analysis shows how a GIS combined with precisely located crash data can be used to quickly identify potentially dangerous driveways with inadequate corner clearance, the omission of crashes due to poor geocoding would skew the analysis indicating a safer situation than actually exists. Further study would allow the user to rank locations based on crash incidence however this ranking may be not be reflective of the actual situation if crash data is omitted due to poor geocoding.

Table 4.7 shows a comparison of the 2012 highway patrol crash data using two different distances: 1) from 0 to 150’ from intersections; and 2) from 150’ to 300’ from intersections. All 6 corridors show that the number of driveway crashes within 150’ of intersections is significantly higher than the number of driveway crashes between 150' and 300' from intersections. The crash rates are also higher in all but one case. It is interesting to note that there are more driveways that fall within the 150 corner clearance, which is not compliant with ARMS, versus the next 150 feet that is compliant.

Table 4.7: Comparison of driveway crashes occurring within 0-150 ft. and 150-300 ft. of an intersection

	# of driveways		**HP 2012 Crashes**		**Crash Rate**	
	0-150ft	**150-300ft**	**0-150ft**	**150-300ft**	**0-150ft**	**150-300ft**
US 1 Richland	238	124	112	32	0.47	0.26
US 25 Greenville	188	141	169	45	0.90	0.32
SC 146 Greenville	53	42	75	38	1.42	0.90
US 176 Richland	117	95	74	63	0.63	0.66
SC 9 Spartanburg	100	74	58	22	0.58	0.30
US 17 Berkeley	113	86	37	5	0.33	0.06

AADT is a significant contributor to crash incidence. As traffic volumes increase, the number of crashes increases (*Duivenvoorden, 2010*). Inadequate driveway corner clearances also have serious adverse effects on traffic operations, traffic safety, and traffic capacity (*Gan et al., 2007*). Using the 2012 driveway crash data within 150' of intersections, a negative binomial model was generated relating crash incidence with AADT and the number of driveways within a corner clearance less than 150 feet. Figure 4.11 shows the safety performance function that resulted from the negative binomial analysis. The figure shows the gradual increase in number of predicted crashes as the number of driveways and AADT increases. The figure also shows that the number of predicted crashes increases dramatically if more than driveway falls within 150 feet of an intersection within the travelway. Driveway groupings were used in the analysis. The chosen groupings in terms of number of driveways with a corner clearance less than 150 feet of an intersection were “one or two”, “three or four”, “five or more” driveways. The figure indicates that the relationship is rising almost linearly for AADT values less than 10,000 and then begins to level off once volumes exceed 20,000 AADT.

An attempt was made to create a negative binomial model using 2010 data but the model could not be created because so few 2010 crashes fell within the driveways that were in the 150 foot corner clearance. Closer inspection of the data showed that a vast majority of the 2010 crashes within the corner clearance were geocoded outside the travelway buffer and thus would not fall within the driveway buffers.

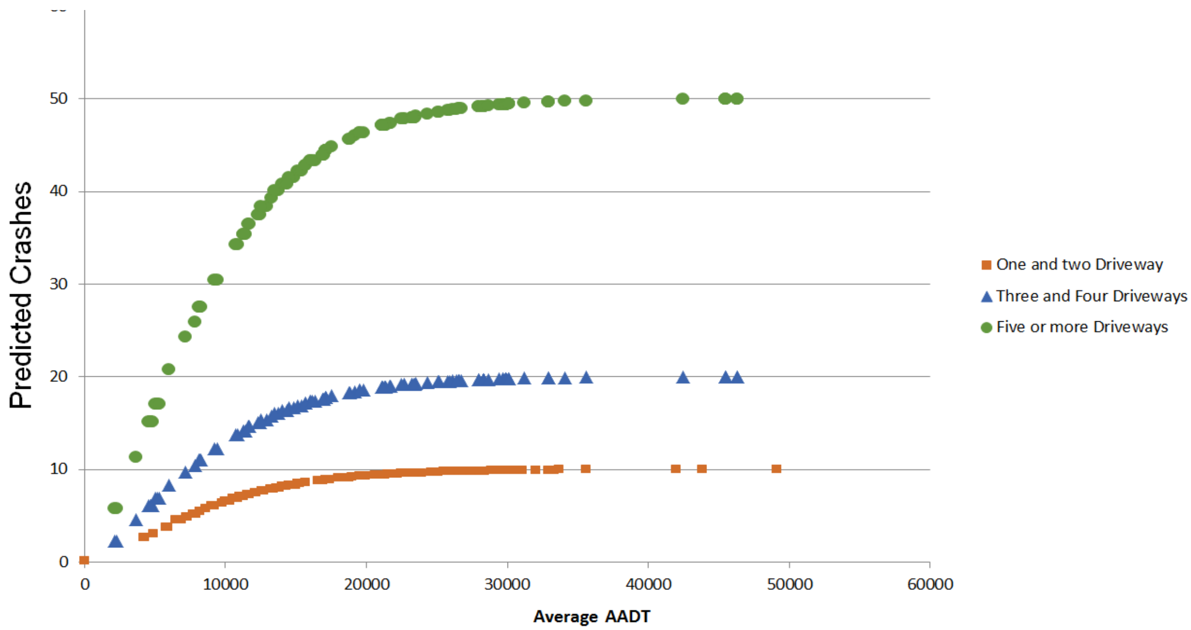


Figure 4.11: Predicted Crashes vs AADT for Driveways within the 150 Ft. Corner Clearance (Negative Binomial)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The two objectives of this research were to 1) identify location problems and accuracy of crash data by analyzing several years of data; and 2) demonstrate how spatially accurate crash data in South Carolina will enhance SCDOT's ability to conduct data-driven transportation safety analysis.

For the first objective, the analysis clearly identified crash location problems and how the accuracy of the crash data improved with SCCATTS. The geocoded crashes comparison figure for "2004 all" and "2012 highway patrol crashes" in South Carolina showed the obvious location problems as evidenced by large number of 2004 crashes geocoded outside of the state boundary. SCCATTS' GIS-based maps enabled with GPS has vastly improved the accuracy and quality of crash data in South Carolina. GIS spatial analysis and case study tabulations support this finding as poor geocoding in the 2010 indicated that more that 50% of the crash locations (not including run-off-the-road and fixed object crashes) occur outside the travelway while the 2011 and 2012 data indicated that the proportion of crashes occurring within the travelway is nearly 100%. The proximity analysis also showed 2010 crashes were further away from their reported route centerline than the 2011 and 2012 crashes thus clearly showed considerable change in the trend of crash locations from 2010 crashes (recorded with a hand-held GPS unit) to 2011 (recorded with SCCATTS).

The second objective to demonstrate how spatially accurate crash data in South Carolina will enhance SCDOT's ability to conduct data-driven transportation safety analysis was achieved by the case study analysis of crash data incidence in close proximity to intersections. This case study analysis of 2010 crash data failed to identify numerous driveway crash clusters, whereas 2012 data readily revealed these patterns. While, the analysis showed how a GIS combined with precisely located crash data can be used to quickly identify potentially dangerous driveways with inadequate corner clearance, the omission of crashes due to poor geocoding may skew the analysis. Additionally, improved crash data quality will enhance other types of safety analysis such as more effective identification and prioritization of specific problem roadway locations and appropriate safety countermeasures. As a result of the new crash reporting procedures, South Carolina has made great strides to improve crash data quality within the state.

Although highway patrol officers are equipped with SCCATTS, a large number of jurisdictions continue to use hand-held GPS units and paper crash reports. Currently, only 60 percent of statewide crashes are reported using SCCATTS. The next steps in the SCDPS and SCDOT effort to collect high accuracy crash data statewide would be to push for the use of SCCATTS in jurisdictions that are not currently using the system. In order to accomplish this goal, SCDOT would first have to educate local officials and law enforcement officers on the benefits of using SCCATTS. The ability to collect spatially accurate statewide crash data in South Carolina will enable the SCDOT in conducting data-driven transportation safety analysis as well as foster other transportation related research resulting in more effective safety programs and policies.

One recommendation for further research is to identify other types of safety analysis done at a macroscopic level that would benefit from precise and accurate crash location.

REFERENCES

1. 2012 Top Crash Location Report, MassDOT http://www.massdot.state.ma.us/Portals/8/docs/traffic/CrashData/12TopCrashLocationsRpt.pdf , Accessed March, 2015.
2. Access and Roadside Management Standards, South Carolina Department of Transportation Traffic Engineering Division, Columbia, SC, 2008. http://www.scdot.org/doing/technicalPDFs/publicationsManuals/trafficEngineering/ARMS_2008.pdf, Accessed March, 2015.
3. Andrew Stokes, "Benefits Of A State Driveway Database with Qualitative and Quantitative Crash Analyses " (2015). All Theses.
4. Anekar, Sukumar, "South Carolina Pole Related crashes - A qualitative and quantitative study" (2010). All Theses. Paper 832
5. Cherry, E., R. Floyd, T. Graves, S. Martin, and D. Ward. "*Crash Data Collection and Analysis System"*. 537, Arizona Department of Transportation, 2006
6. Chowdhury, M., N. Derov, P. Tan, and A. Sadek. “Prohibiting Left-Turn Movements at Mid-Block Unsignalized Driveways: A Simulation Analysis”. ASCE Journal of Transportation Engineering, Vol. 131, No. 4, 2005, 279-285
7. Crash Data Improvement program Guide, U.S Department of Transportation Federal Highway Administration, April 2010 http://safety.fhwa.dot.gov/cdip/finalrpt04122010/finalrpt04122010.pdf, April 2015
8. Duivenvoorden, K. “The Relationship Between Traffic Volume and Road Safety on the Secondary Road Network”, D-2010-2, 2010

9. Fatality Analysis Reporting System (FARS) - National Highway Traffic Safety Administration (NHSTA). Traffic Safety Facts South Carolina, 2007-2011. http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/STSI/45_SC/2011/45_SC_2011.htm, Accessed June/03, 2013
10. Federal Highway Administration (FHWA) Office of Safety. Roadway Safety Professional Capacity Building (RSPCB) - Peer-to-Peer Program. FHWA, 2011
11. Gan, C. and Long, G. "Effects of Inadequate Driveway Corner Clearances on Traffic Operations, Safety, and Capacity", paper No. 970542, TRB 1579, 2007
12. Havlicek, J.P. and Barnes R.D. "GPS Location Data Enhancement in Electronic Traffic Records", Oklahoma Transportation Center, Economic Enhancement through Infrastructure Stewardship. OTCREOS11.1-27-F, 2012
13. Li, L., and Zhang, Y. "Bayesian Approach Based on Geographic Information System to Identify Hazardous Roadway Segments for Traffic Crashes". Transportation Research Record: Journal of the Transportation Research Board, No. 2024, 63-72, 2007
14. McNeil, N. and Edeman, A. "Vehicular Crash Analysis in Washington County, Oregon, USP 531 Final Project, march 16, 2009
15. Miller, J. S. "What Value May Geographic Information Systems Add to the Art of Identifying Crash Countermeasures?" VTRC 99-R12 Charlottesville, VA, 1999
16. National Cooperative Highway Research Program. *NCHRP Synthesis 367 - Technologies for Improving Safety Data.* NCHRP Synthesis 367, Transportation Research Board (TRB), 2007.

17. Qin, X. and Schieldt K. “A Look at the Wisconsin Department of Transportation’s (WISDOT) Use of Statewide Crash Mapping Capabilities”, A Newsletter from the Federal Highway Administration (FHWA), 2013
18. Research and Innovative Technology Administration (RITA) - Bureau of Transportation Statistics (BTS). State Transportation Statistics - Safety. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2011/index.html, Accessed June/03, 2013.
19. Sarasua, W., J. Ogle, and K. Geoghegan. "Use of Global Positioning System to Identify Crash Locations in South Carolina". *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2064, No. -1, 2008, pp. 43-50
20. Smith, R., A. J. Graettinger, K. Keith, M. Hudnall, and A. Parrish. Using GIS for Law Enforcement. *Journal of Safety Research*, Vol. 36, No. 5, 2005, pp. 477-479
21. South Carolina Department of Public Safety. South Carolina Traffic Collision Fact Book 2012. http://www.scdps.gov/ohsjp/fact%20book/2012%20Fact%20Book.pdf, Accessed March/17, 2015.
22. South Carolina Department of Transportation (SCDOT). *A Strategic Highway Safety Plan: The Road Map to Safety*. South Carolina Department of Transportation (SCDOT), South Carolina, 2007
23. Stantec, and CDM Smith. "*South Carolina Multimodal Transportation Plan: Safety and Security*. South Carolina Department of Transportation, 2013"