GEORGIA DOT RESEARCH PROJECT 12-04

FINAL REPORT

Design Exception In-Service Monitoring Program Development

Georgia Department of Transportation

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16. Abstract:
This study evaluates various possible program designs for in-service monitoring of design exceptions (DEs) for the Georgia Department of Transportation. The study recommends a multi-tier stepwise approach to the evaluation of DEs. Specifically, the proposed monitoring program aims to: (1) identify DE-associated hazards that have/could result in a fatality or serious injury at a site, (2) detect and identify DE-related increases in crash rate, and (3) detect and identify any DE-related increase in crash severity. The proposed program was designed to minimize additional data collection requirements and ongoing time and resource requirements for implementation. An important step in minimizing these resource requirements is to ensure that the information necessary for conducting these future audits is available early in the design exception review process. The proposed changes to the design exception request process are relatively minor but will pay important dividends in reducing future monitoring costs. In particular, these process changes should be implemented as soon as possible.

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GDOT Research Project 12-04

Final Report

DESIGN EXCEPTION IN-SERVICE MONITORING PROGRAM DEVELOPMENT

By

Michael Hunter, Ph.D., Associate Professor (P.I.)
Michael Rodgers, Ph.D., Principal Research Scientist (Co-P.I.)
Yanzhi (Ann) Xu, Ph.D. Research Scientist II
Audrey Leous, Research Scientist I
Charlene Mingus, Research Scientist I
Samuel Sim, Graduate Research Assistant
Laura Stahley, Graduate Research Assistant

School of Civil and Environmental Engineering and
Georgia Institute of Technology

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Abbreviations

AADT	annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
CMF	crash modification factor
DE	design exception
DOT	Department of Transportation
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GeoPI	Transportation Project Information
GIS	geographic information system
HSM	Highway Safety Manual
INDOT	Indiana Department of Transportation
KTC	Kentucky Transportation Center
NB	negative binomial
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
PDO	property damage only
PoDI	Project of Division Interest
PDP	*Plan Development Process*
PM	project manager
RC	Roadway Characteristics

SPF	safety performance function
SR	State Route
SSD	stopping sight distance
UDOT	Utah Department of Transportation
WSDOT	Washington State Department of Transportation

Symbols

Y	Number of crashes at a site for a given year
$NB(\mu, \theta)$	Negative binomial distribution of the count random variable Y
$\Gamma(\cdot)$	Gamma function
$E(Y) = \mu$	Mean of Y
$V(Y) = \mu + \mu^2/\theta$	Variance of Y
$X_1, \ldots, X_m$	Yearly crash frequencies after the DE
$NB(\mu_Y, \theta_Y)$	Probability mass function
$\Psi(\cdot)$	Digamma function
z_α	The $(1-\alpha)100th$ percentile of a standard normal distribution

Executive Summary

A design exception (DE) is a documented design decision that is made when the minimum/maximum value or range of values for a controlling design criterion cannot be met. The U.S. Federal Highway Administration (FHWA) provides guidance on flexible design decisions to satisfy the minimum, maximum, or range of values set aside for certain controlling design criteria. Historically, there were 13 controlling design criteria (Harwood et al., 2014) established by FHWA.. On May 5, 2016, FHWA reduced this number to 10 (Federal Highway Administration, 2016). Both sets of criteria are illustrated below:

FHWA Controlling Design Criteria	
Pre-2016 Controlling Criteria	*Current Controlling Criteria*
1. Horizontal Alignment 2. Shoulder Width 3. Vertical Alignment 4. Horizontal Clearance 5. Lane Width 6. Superelevation 7. Stopping Sight Distance 8. Grade 9. Bridge Width 10. Design Speed 11. Cross Slope 12. Vertical Clearance 13. Structural Capacity	1. Design Speed 2. Design Loading Structural Capacity 3. Stopping Sight Distance 4. Horizontal Curve Radius 5. Maximum Grade 6. Vertical Clearance 7. Super-elevation Rate 8. Lane Width 9. Cross Slope 10. Shoulder Width

In practice, however, engineers and designers must balance several key factors in the design of roadways and supporting infrastructure, including cost, safety, mobility, as well as social and environmental impacts (Stein & Neuman, 2007). The controlling criteria cannot always be met when considering these other factors, and in these cases a DE may be proposed. Based on

FHWA guidance, state departments of transportation including the Georgia Department of Transportation (GDOT) have formal procedures for approving DE requests to ensure that the proposed design will not compromise roadway safety. Although FHWA recommends that state DOTs monitor and evaluate the in-service performance of DE sites, there are, at present, no state-level DE in-service monitoring programs. The primary goal for this research project was to develop a DE in-service monitoring program for GDOT to enable evaluation of the in-place performance of DE sites and ensure that the objectives of the DE process are being met.

Study Objectives

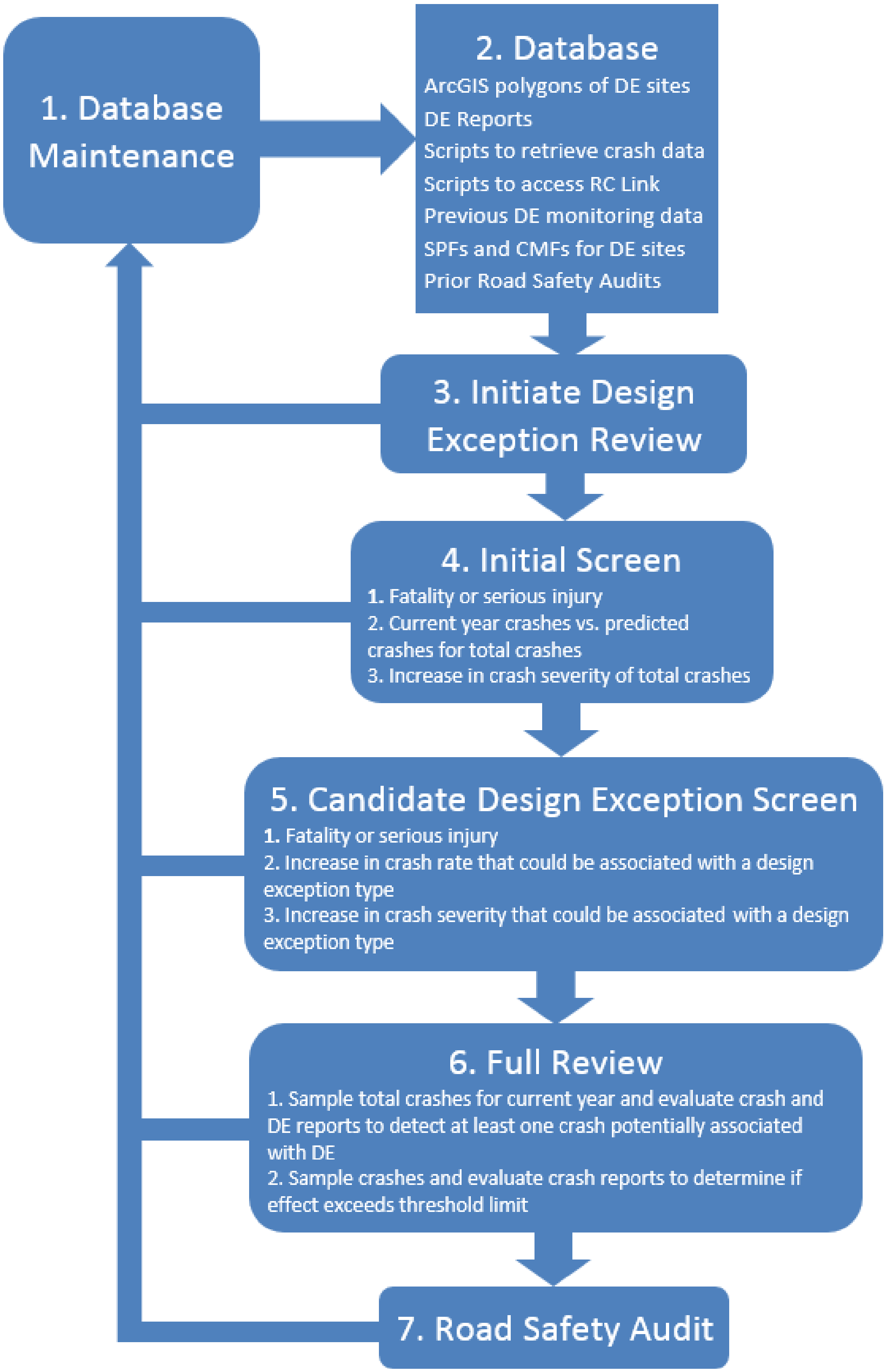
This study had three primary objectives:

1. Analyze the safety performance of selected roads with existing DE sites
2. Evaluate the ability to implement Highway Safety Manual (HSM) procedures to estimate crash frequencies associated with design exceptions
3. Recommend future DE in-service monitoring and evaluation procedures for GDOT

The third objective, the proposed DE in-service monitoring program, provided the main thrust of this study since developing and evaluating the statistical methods (largely derived from HSM approaches) to be used in the proposed program effectively met the second objective and will not be significantly impacted by the 2016 change in the controlling criteria. Similarly, a case study of the proposed program approach (provided in Appendix A) substantially met the requirements of the first objective.

The proposed in-service monitoring program (illustrated in the following figure) aims to: (1) identify DE-associated hazards that have resulted or could result in a fatality or serious injury at a site, (2) detect and identify DE-related increases in the crash rate at a DE site, and (3) detect and identify any DE-related increase in the severity of crashes at a project location. The research team specifically designed the proposed DE in-service monitoring program to avoid significant additional data collection requirements and to minimize ongoing time and resource requirements for implementation, while maintaining a robust statistical approach to ensuring roadway safety in the DE process.

An important step in minimizing these resource requirements is to ensure that the information necessary for conducting these future audits is available early in the design exception review process. The proposed changes to the design exception request process are relatively minor but will pay important dividends in reducing future monitoring costs. These process changes should be implemented as soon as possible.



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Introduction

Background and Purpose

A design exception (DE) is a documented design decision that is made when the minimum/maximum value or range of values for a controlling design criteria cannot be met. The U.S. Federal Highway Administration (FHWA) provides guidance on flexible design decisions to satisfy the minimum, maximum, or range of values set aside for certain controlling design criteria. Historically, FHWA established 13 controlling criteria (Harwood, et al., 2014) however, recently (May 5, 2016) the number of controlling criteria was reduced to 10 (Federal Highway Administration, 2016) both sets of criteria are illustrated in Figure 1.

FHWA Controlling Design Criteria	
Pre-2016 Controlling Criteria	*Current Controlling Criteria*
14. Horizontal Alignment 15. Shoulder Width 16. Vertical Alignment 17. Horizontal Clearance 18. Lane Width 19. Superelevation 20. Stopping Sight Distance 21. Grade 22. Bridge Width 23. Design Speed 24. Cross Slope 25. Vertical Clearance 26. Structural Capacity	11. Design Speed 12. Design Loading Structural Capacity 13. Stopping Sight Distance 14. Horizontal Curve Radius 15. Maximum Grade 16. Vertical Clearance 17. Super-elevation Rate 18. Lane Width 19. Cross Slope 20. Shoulder Width

Figure 1: FHWA Controlling Design Criteria

In practice, however, engineers and designers must balance several key factors in the design of roadways and supporting infrastructure, including cost, safety, mobility, as well as social and environmental impacts (Stein & Neuman, 2007). The controlling criteria cannot always be met when considering these other factors, and in these cases a DE may be proposed. Based on FHWA guidance, state departments of transportation including the Georgia Department of Transportation (GDOT) have formal procedures for approving DE requests to ensure that the proposed design will not compromise roadway safety. Despite being relatively common, minimal research has been conducted on the effect of various DE types on roadway safety, as these studies are constrained by availability of necessary data and high resource requirements

Although FHWA recommends that state DOTs monitor and evaluate the in-service performance of DE sites, there are, at present, no state-level DE in-service monitoring programs. The primary goal for this research project was to develop a DE in-service monitoring program for GDOT to enable evaluation of the in-place performance of DE sites and ensure that the objectives of the DE process are being met.

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The third objective, the proposed DE in-service monitoring program, provided the main thrust of this study since developing and evaluating the statistical methods (largely derived from HSM approaches) to be used in the proposed program effectively met the second objective. The change from the 13 controlling criteria to the 10 new criteria, although significant in the design exception approval process will have no significant impact on the proposed monitoring program. Similarly, a case study of the proposed program approach (provided in Appendix A) substantially met the requirements of the first objective.

The proposed in-service monitoring program aims to: (1) identify DE-associated hazards that have resulted or could result in a fatality or serious injury at a site, (2) detect and identify DE-related increases in the crash rate at a DE site, and 3) detect and identify any DE-related increase in the severity of crashes at a project location. The research team specifically designed the proposed DE in-service monitoring program to avoid significant additional data collection requirements and to minimize ongoing time and resource requirements for implementation, while maintaining a robust statistical approach to ensuring roadway safety in the DE process.

The Current Design Exception Process

This section summarizes the current GDOT process for documenting a DE, and discusses how the proposed DE in-service monitoring program will build upon this process by proposing updated forms and procedures.

Federal Design Exception Process

The FHWA is designated by federal regulation to establish design standards that are applied to the National Highway System (NHS). The FHWA requires a formal process to be completed for a DE, whether the project is funded federally or with state or local funds, when the design values do not meet the established minimum 13 controlling criteria values or ranges of values (Stein & Neuman, 2007). To help guide state DOTs through this process, the FHWA published a guidance document, *Mitigation Strategies for Design Exceptions*, in 2007 offering additional information and important strategies to mitigate potential negative effects that may be caused as the result of DE types. Figure 2, taken from that publication, illustrates this process.

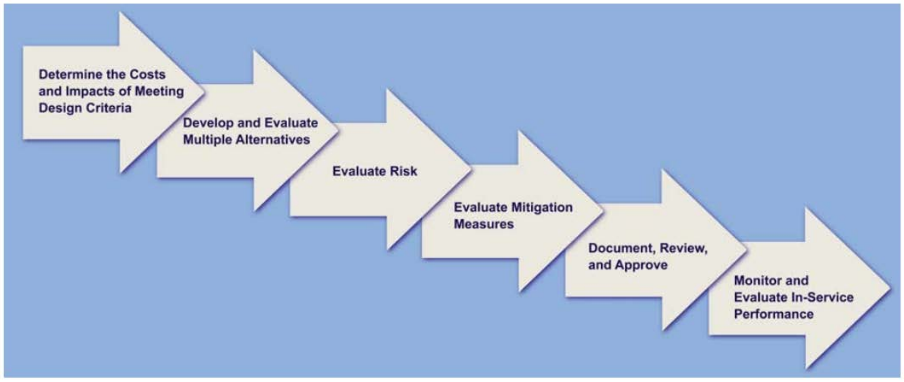

Figure 2: Illustration of the Federal Highway Administration Design Exception Process; Adopted from *Mitigation Strategies for Design Exceptions* (Stein & Neuman, 2007)

The focus of this research is on the final step in this process: Monitor and Evaluate In-Service Performance. In practice, the current extent of in-service evaluation varies due to limited budgets, human resources, or other factors (Stahley, 2013). This is expected, as the rare and random nature of crashes implies that several years of crash data must be collected before any correlations can be made between DE types and their impacts on safety (Stein & Neuman, 2007).

Considering how safety is affected by DE types is arguably the greatest concern when making the decision to accept or reject a proposed DE site. Nominal safety is an "either-or" condition that states whether or not a roadway, design alternative, or design element meets the minimum or maximum design criteria (Stein & Neuman, 2007). If the design features of a project meet the minimum values, maximum values, or ranges of the 13 controlling criteria, the project is considered nominally safe (Sim, 2012). By definition, roadways, design alternatives, or design elements that require a DE and do not satisfy at least the minimum design criteria cannot be classified as nominally safe. This does not mean that the road is unsafe, since the actual safety performance of a highway must be observed over time, but rather it does not fully meet accepted design criteria.

Substantive safety is defined as the "actual long-term or expected safety performance of a roadway," (Stein & Neuman, 2007) and can be measured quantitatively by observing crash frequency, crash type, and crash severity. Since the concept of substantive safety reflects "real world" performance of the system, it is a criterion that should be used in assessing safety impacts when making sound decisions to accept or approve a DE (Stein & Neuman, 2007).

By formally comparing a location or highway's crash profile with facilities with similar characteristics, judgments about substantive safety and whether or not the DE will meet safety expectations can be made. This formal comparison generally involves applying statistical models of crash experience from broader data sources, such as from sites in the same jurisdiction as the site being studied (Stein & Neuman, 2007).

The key to understanding the concepts of nominal and substantive safety is to recognize that they are not necessarily dependent upon one another. Although a roadway that meets all minimum design criteria is nominally safe, it may demonstrate high crash statistics that make it substantively unsafe. Conversely, a roadway that is nominally unsafe may function at a high level of substantive safety. The reason for this discrepancy is that the 13 controlling criteria are based on simplified models and are broadly applied to situations that, in reality, depend on a multitude of other factors, as well (Federal Highway Administration, 1997b). Figure 3 illustrates the concept of nominal and substantive safety with respect to their crash risk models. Clearly, small changes in the design dimensions of a project result in small changes to crash risks. Designers and engineers should seek to achieve the highest level of substantive safety while striving to meet design criteria to the extent to which they apply (Stein & Neuman, 2007).

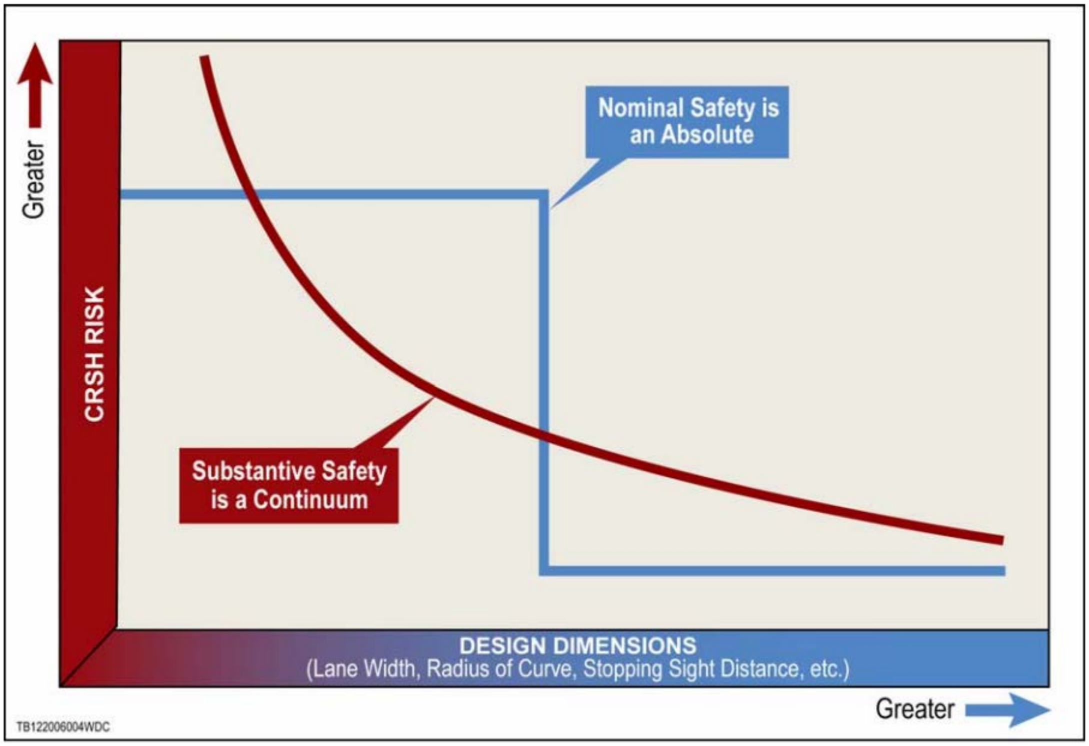

Figure 3: Relationship between Nominal and Substantive Concepts of Safety with Respect to Design Dimensions and their Effects on Crash Risks (Federal Highway Administration, 2007c)

State DOT Design Exception Process

All state DOTs have adopted *A Policy on Geometric Design of Highways and Streets* (i.e., "*Green Book*") published by the American Association of State Highway and Transportation Officials (AASHTO) as their primary reference in roadway design. In addition, most state DOTs produce their own state-specific design manuals to reflect the standard practices for their particular state conditions. Most of these state manuals begin by adopting FHWA's 13 controlling criteria as standards within their own departments. When designs deviate from these controlling criteria, the approval of a DE is required by the Federal Highway Administration (Federal Highway Administration, 1997a). Thus, state DOT design manuals typically also include sections outlining their specific DE approval process for projects that are both located on and off the NHS.

As part of this project, researchers examined these state-specific manuals to identify similarities in the process and documentation of DE types by state DOTs. Although DEs are usually discouraged, these manuals usually provide steps on completing the DE approval process in a similar format that can be represented by six questions:

1. When is a DE required?
2. When should the need for a DE be identified?
3. How should the DE be documented? What data/forms are necessary?
4. Who is responsible for approving the DE?
5. Where should the DE be filed?
6. What is the process if the DE is denied? (Nunez, 2012)

In compliance with current federal regulations (23 CFR 625.3), most of these manuals state that the projects requiring a DE are: (1) new highway construction; (2) existing highway reconstruction for lane addition, acceleration and deceleration lanes, and pavement replacement; (3) total bridge replacements on the NHS; and (4) bridge widening projects (Federal Highway Administration, 1997a). The restorations of locations where DE requests have already been filed usually do not require an additional DE process to be completed. Each state has DOT-specific forms for documenting a DE, but they generally contain the same required information. Engineers must provide the reason for approval, the alternatives considered, mitigation processes explored, and sometimes crash analyses to accompany their forms. Approval is typically required of both the chief engineer and the engineer of record responsible for the project. For *Projects of Division Interest* (PoDI, e.g. those on the NHS), FHWA approval must also be obtained (Federal Highway Administration, 1997a). After the process is completed, the DE forms and approval signatures are kept on file with the respective offices and agencies in charge of the project. New Jersey and Utah are the only states that currently offer a standalone DE manual, each of which were published in 2012 (Porter & Wood, 2012) (New Jersey Department of Transportation, 2012).

In addition to the 13 controlling criteria, several state DOTs (including Georgia) have developed their own additional design standards (criteria) that must be met as part of an approved design. Many state DOTs, including GDOT, refer to these additional design criteria as *standard criteria*. The documented decisions to accept minimum or maximum values outside the ranges stated in DOT-specific manuals are generally referred to as *design variances,* whereas *design exceptions* refer to deviations from the 13 FHWA controlling criteria. In a review of road design manuals, the only difference in terminology appeared in Alaska and Minnesota, where they are called *design waivers* and *informal DEs,* respectively (Nunez, 2012).

In the review of design manuals, a major component missing from guidance is the process required when a DE request is denied. Many state DOT manuals mention that the process must be filed regardless of whether or not a DE request is approved. They do not mention if the chief engineer will explain whether or not it is approved, or what can be done to gain approval if a request has been denied. Based on the guidance provided by the state DOT manuals, it is not clear whether there is an appeal process for denied DE requests. It is assumed that designers must find an alternative design or determine additional reasons to file for the DE again.

The GDOT Design Exception Process

Similar to other states, the Georgia Department of Transportation adopted the 13 controlling criteria (Figure 1) identified by FHWA as having substantial importance in highway design, as well as the corresponding minimum values set in place by AASHTO as its primary road design standard (Georgia Department of Transportation, 2007). In addition, GDOT maintains a publication entitled *GDOT Plan Development Process* (PDP) that assists project managers when carrying out their duties and responsibilities for project development, including outlining the process of documenting a DE and/or design variance (DV) (Georgia Department of Transportation, 2011). When these minimum values are not met, the DE process outlined in both the PDP and by FHWA is followed. GDOT has identified 15 additional design elements, known as “standard criteria,” that should also be reviewed during the design process (see Table 1). When the criteria of these design elements are not met, a “design variance” must be approved by the

GDOT chief engineer, and the procedures outlined in the PDP must be followed. A design variance must also be approved for non-PoDI projects that do not meet the 13 controlling criteria or GDOT's standard criteria.

Approval of a DE (i.e., when values are outside the 13 AASHTO controlling criteria) as outlined by the GDOT PDP begins with the engineer of record preparing a DE request and forwarding it to the GDOT project manager assigned to the project. Upon receiving and reviewing the request, the project manager forwards the package and his/her recommendations to the Office of Design Policy and Support. The Office of Design Policy and Support likewise conducts a review and forwards the information and its recommendations to the GDOT Director of Engineering and the GDOT Chief Engineer and, if the project is PoDI, to the FHWA for final approval or disapproval. A similar process is followed when documenting a design variance (i.e., deviation from the 15 GDOT standard criteria).

After approval, GDOT does not specifically require a monitoring process for evaluating the in-service performance and impact of a DE after the completion of the project. Figure 4 shows a flowchart of this process.

Table 1: Additional Standard Design Criteria as Defined by GDOT to Consider in Roadway Design (Georgia Department of Transportation, 2007)

	Standard Criteria
1	Access Control
2	Intersection Sight Distance
3	Intersection Skew Angle
4	Tangent Lengths on Reverse Curves (Design Speed >= 50)
5	Lateral Offset to Obstruction
6	Shoulder Width
7	Rumble Strips
8	Safety Edge
9	Median Usage
10	Roundabout Illumination Levels
11	Pedestrian and Bicycle Warrants
12	ADA Requirements
13	GDOT Construction Standards
14	GDOT Drainage Manual
15	GDOT Bridge & Structural Manual

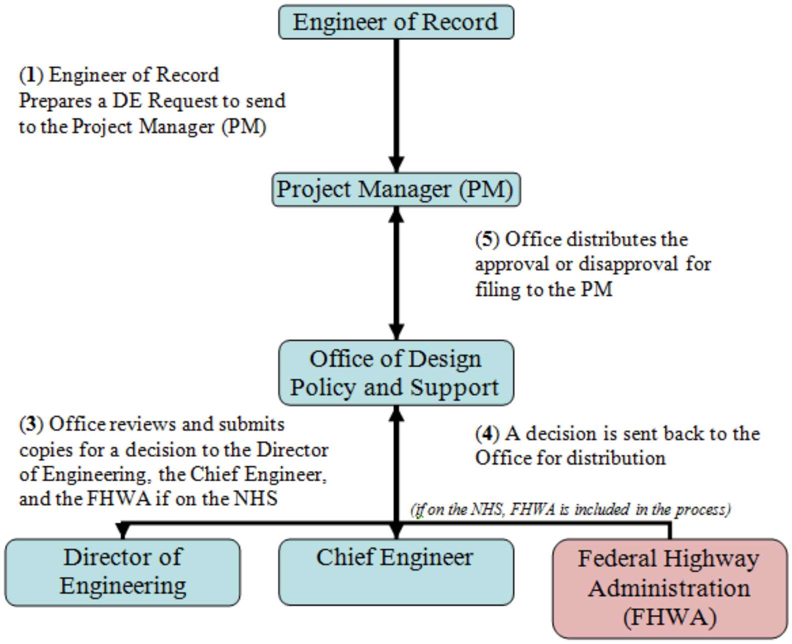

Figure 4: Georgia Department of Transportation Design Exception Filing Process (Georgia Department of Transportation, 2007)

Previous Research Conducted on the Safety Effects of DE Types

As discussed, there has been relatively little research on the safety impact of specific types of DEs. Some of the more important contributions to this research are outlined below.

National Cooperative Highway Research Program 400: Determination of Stopping Sight Distances

To reevaluate the stopping sight distance (SSD) design policy of the 1994 AASHTO *Green Book*, the National Cooperative Highway Research Program (NCHRP) performed field, safety, and operational studies of driver performance, driver visual capacity, driver eye heights, and vehicle heights (Fambro, Fitzpatrick, & Koppa, 1997). As a result of these recommended revisions, the *Green Book* was updated in 2004 with a new policy to determine stopping sight distances. The change in this policy affected the acceptable “k” values used in vertical alignment. There are a significant number of design exceptions in the state of Georgia on projects in locations where the roadway design meets the 1994 standard, but was not updated to comply with the 2004 standard. It would be difficult to try to determine whether or not accident rates increased at locations of design exceptions where conditions stayed the same both before and after construction. The results of the NCHRP 400 state that there were no findings to suggest that a change in stopping sight distance determination affected accident rates.

National Cooperative Highway Research Program: Evaluation of the 13 Controlling Criteria for Geometric Design

The NCHRP recently completed a study of how the 13 controlling criteria established by FHWA in 1985 have affected safety and operations as part of a reevaluation of these criteria, and the associated recommendations have been made available in a draft form (Harwood, et al., 2014). As the design for future projects must be customized to fit particular situations more and more, the appropriateness of the current controlling criteria is being evaluated based on new knowledge that has been gained since their implementation. In particular, the draft report recommends drastically altering the design process and largely replacing the controlling criteria with a "performance-based" approach. Whether the existing criteria will be retained or new criteria developed will be determined by AASHTO and FHWA over the coming years. The decisions based on these recommendations will have significant implications for the design exception process and may ultimately require its replacement by an alternative method of documenting the impact of designs on highway safety. Nevertheless, the procedures recommended here, which evaluate the actual impact of design features, will likely continue to be relevant in the implementation of any future system.

Perceptions of Design Exception Performance

A 2003 NCHRP report presented findings from a survey of 46 transportation agencies across the country (Mason, Jr. & Mahoney, 2003). This survey focused on the *perception* of the efficacy of the design exception process, rather than an analysis of design exception performance.

The reported primary benefits of the design exception review process are that it provides a record of the decision process and, in conjunction, can be useful in managing tort risk. Table **2** summarizes survey respondents' perceptions of benefits.

Table 2: Benefits of Design Exceptions, As Reported by Survey Respondents (Mason, Jr. & Mahoney, 2003)

Percentage	Benefit Cited
42%	Reduces Liability Exposure
40%	Design Exception Documentation
6%	Improves Safety
6%	Future Reference Material
6%	Other

The survey also highlighted the difficulties encountered by transportation agencies: lack of agency support, design exception review process being too cost- and time-intensive, inadequate guidance on submitting design exceptions, and the timing of submittal in comparison to the project status.

A 2009 NCHRP study also presents information on the perceptions of local agencies and state DOTs on design exceptions (NCHRP, 2009). The results of this survey are more varied than the results of the 2003 NCHRP survey. Most local agencies that responded to the survey felt that design exceptions generally have a "neutral to positive effect on the project performance," while state DOT respondents felt that design exceptions led to poorer project performance (NCHRP, 2009). This report indicated that some agencies do review project performance after implementation, but the report provided no further information to this point. The report noted that there were insufficient data to draw a firm conclusion on the effect of design exceptions on safety, but that most agencies do not perceive a negative impact on safety performance.

Washington State Department of Transportation: In-Service Evaluation of Major Urban Arterials with Landscaped Medians—Phase II

One example of how new criteria have developed in the field was provided by the Washington State Department of Transportation (WSDOT) in 2004, when an in-service evaluation was done on major urban arterials with landscaped medians (Brigilia Jr., Hallenbeck, Howard, & Martin, 2013). While attempting to redevelop some of the arterials, such as State Route (SR) 99 north and south of Seattle, developers considered increasing road safety, creating aesthetically pleasing environments, and enhancing the attractiveness of the region and communities. In the process, the criteria that WSDOT set for clear zone width on streets were not always achieved due to trees placed in curbed medians. To support aesthetic designs, WSDOT chose to implement an in-service evaluation of landscaped medians to study and determine that the safety impacts were insignificant. Though clear zone width is not one of the current 13 controlling criteria implemented by FHWA, future studies done on their impacts in relation to safety could pave the way for its implementation.

Kentucky Transportation Center: Safety Implications from Design Exceptions

The Kentucky Transportation Center (KTC) conducted a study by observing crash data evaluating the negative safety implications that occur from design exceptions. During the eight-year period from 1993 to 2000, there were 319 design exceptions filed with the Kentucky DOT (Agent, Pigman, & Stamatiadis, 2002). After narrowing down project sites, 65 sampled project sites were analyzed based on the availability of crash data. The KTC concluded that implemented design specifications other than those typically used did not negatively affect the level of safety of the project for 59 of the 65 sampled sites (Agent, Pigman, & Stamatiadis, 2002). The KTC recommended additional research on (1) safety consequences for specific crash types, (2) analyzing the severity of crashes, and (3) the comparison of relatively similar roadways constructed with and without design exceptions, once additional data become available (Agent, Pigman, & Stamatiadis, 2002).

Indiana Department of Transportation: Safety Effects of Design Exceptions

The Indiana Department of Transportation (INDOT) stratifies their design exceptions into three levels of highway design criteria based on the severity of their effect on safety and serviceability (Malyshkina, Mannering, & Thomaz, 2009). Level One includes 14 design criteria that are believed by INDOT to have the largest effect on highway safety and serviceability: design speed, lane widths, shoulder widths, bridge width, bridge structural capacity, horizontal curvature, superelevation transition lengths, stopping sight distance on horizontal and vertical curves, maximum grade, superelevation rate, minimum vertical clearance, accessibility for the handicapped, and bridge rail safety. INDOT researched the safety impacts of design exceptions by performing a statistical analysis on crash severity and frequency on roadway segments that had both received and not received design exceptions that fell into the Level One category.

INDOT analyzed 36 Level One design exceptions that had been approved from 1998 to 2003, as well as 71 control sites without design exceptions. The control sites were chosen according to their location and similarities relative to the 36 design exception project sites. The potential impact of design exceptions on crash frequency and severity was determined by observing accidents that occurred during a five-year period from January 1, 2003, to December 31, 2007, at the 36 design exception sites and 71 control sites. INDOT used negative binomial regression and a multinomial logit model to analyze the data and concluded that the design exceptions did not have a “statistically significant adverse effect on the frequency or severity of accidents” (Malyshkina, Mannering, & Thomaz, 2009). In the report, INDOT recognizes the limits of researching the effect of design exceptions of safety due to the limited amount of data available at the time; however, INDOT encourages further research as additional data become available.

Utah Department of Transportation: Safety Impacts of Design Exceptions in Utah

Similar to the methodology used by INDOT, the Utah Department of Transportation (UDOT) quantified crash frequency and severity on road segments where design exceptions had been approved. UDOT compared the road segments with design exceptions to relatively similar road segments without exceptions, which acted as control sites and allowed comparative analysis of safety impacts (Porter & Wood, 2012). Sixty-three UDOT-approved projects with design exceptions were built from 2001 to 2006. A majority of these projects were located on road segments. Bridges, intersections, and interchanges with design exceptions that had been built from 2001 to 2006 were excluded from the analysis because there were not enough sites represented in the sample to allow meaningful analysis. As a result, a total of 48 road segment projects were studied that averaged 1.77 design exceptions per road segment with a maximum of five design exceptions and minimum of one design exception (Porter & Wood, 2012). The table below from UDOT's final report shows the design exception frequencies of their study.

Table 3: Distribution of the Sample Set of Design Exceptions Used in the UDOT Study on the Safety Impacts of Design Exceptions

Criteria	Count	Criteria	Count
Design Speed	3	Cross Slope	6
Lane Width	7	Stopping Sight Distance	7
Shoulder Width	24	Structural Capacity	0
Superelevation	7	Bridge Width	0
Horizontal Alignment	8	Vertical Clearance	2
Vertical Alignment	9	Horizontal Clearance	7
Grade	6	Total Exceptions	86

For each project site chosen in the study, UDOT chose for comparison a minimum of two control locations with relatively similar geometric designs. To evaluate the adequacy of the comparison sites, propensity scores were generated to eliminate bias from the selection process. This resulted in the selection of 132 control segments that were used in the modeling processes for crash severity and frequency. In addition, UDOT provided crash data from 2006 to 2008 to analyze the safety impacts of the design exceptions. A negative binomial regression model was used for crash frequency analysis, which takes into account highway geometric design variables that are left out by traditionally used Poisson regression analyses (Porter & Wood, 2012). Crash severity was analyzed using three methods to prevent bias and over- or under-estimating safety impacts: (1) computing severity distributions at locations with or without design exceptions, (2) producing separate negative binomial regression models by crash severity levels, and (3) using a multinomial logit model. The first two methods are explained in the *Highway Safety Manual* (American Association of State Highway and Transportation Officials, 2010b), while the multinomial logit model is a discrete choice model that is widely used in the field. UDOT concluded that there was no significant difference in the distribution of crashes along the segments constructed from 2001 to 2006 with design exceptions and without design exceptions.

Safety Impacts on Non-Freeway Segments

Wood and Porter present the results of comparing safety on road segments with approved design exceptions to safety on similar road segments without any design exceptions (Wood & Porter, 2013). Using data on design exceptions in Utah from 2001 to 2006, they found no significant differences in either crash frequency or severity between road segments with design exceptions and those without.

Proposed Monitoring Program

Overview

The primary purpose of this study was to develop and recommend an ongoing in-service monitoring program to ascertain any potential issues arising from the incorporation of DE into the roadway design process. This section provides an overview of the operation of the proposed program. A case-study demonstration of how the process works with actual data from historical DE sites is provided in Appendix A. Other supporting information necessary for implementation of the program and a more formal theoretical statistical framework for the proposed program are provided in later appendices.

The DE monitoring program focuses on: (1) identifying DE-associated hazards that have resulted, or could result, in fatality or serious injury; (2) detecting and identifying potentially DE-related increases in the crash rate at a DE site; and (3) detecting and identifying potentially DE-related increases in the severity of crashes at the DE site. The proposed DE monitoring program (Figure 5) consists of seven major elements: (1) DE monitoring database maintenance; (2) DE monitoring database for current annual evaluation; (3) initiation of DE review, determining if there were any crashes at the DE site during the study period; (4) initial screen; (5) candidate DE screen; (6) full review; and (7) road safety audit. Figure 5 illustrates the seven major sections of the DE monitoring program, while a detailed flowchart is included in Figure 6.

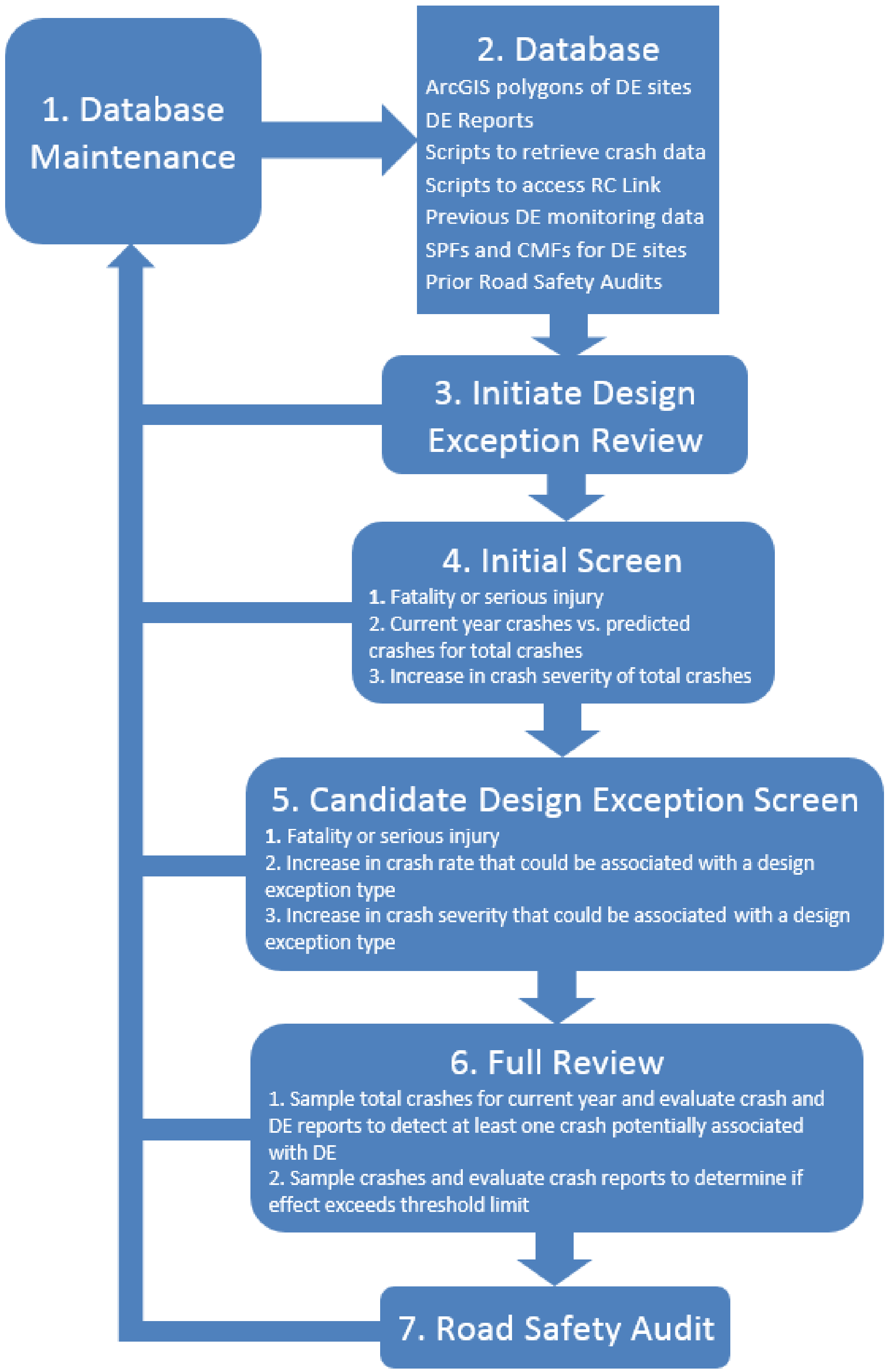

Figure 5: Proposed Design Exception Monitoring Program Methodology

Figure 6: Details of DE Monitoring Program Methodology

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Step One: Ongoing Design Exception Monitoring Data Maintenance

The backbone of the proposed monitoring program is a DE ArcGIS® polygon shapefile and associated attribute table (Table 4), referred to as the DE Layer, that is maintained on an ongoing basis. Information about all DE sites is stored in the DE Layer, including: (1) DE sites that have been built and are being monitored, (2) DE sites that have been built but are not being monitored, and (3) DE sites that have been approved but construction has not been completed. Figure 7 outlines the process of creating the DE Layer. An example DE Layer (provided in Appendix A as supplemental material to this report) was created to illustrate how such a shapefile should be constructed and to support the case study described in Appendix A. The DE Layer includes the information listed in Table 4, along with the Traffic Layer and Crash Layers, and provides the necessary information for subsequent steps in the DE analysis.

The DE Layer will need to be updated on at least an annual basis to incorporate new DE sites by adding new DE buffer polygons and attribute information through the process outlined in Figure 7. First, a unique DE site ID will be assigned to each new DE location as the information is added to the database, since a project may contain multiple DE locations. Each DE site requires a unique ID as the sites need to be analyzed individually.

For the case study provided in Appendix A, the DE site boundaries were created using the data that were currently available to the researchers (i.e., latitude and longitude data were not available for these sites) through a tedious manual process. However, future updates should be able to use the latitude and longitude data provided in the proposed DE request form to locate the DE site boundaries and thereby simplify this process. A DE site will have one set of coordinates for a DE that is located at an intersection and two sets of coordinates (at the endpoints) for a DE that occurs along a segment (e.g., a curve radius). Appendix C1 includes a revised version of the DE request form with the addition of requiring the latitude and longitude of the DE site boundaries, among other edits.

Table 4: Design Exception GIS Layer: Proposed Attributes

Data Type	Attribute	Data Source	DE Site
DE Information	Unique DE ID	Generated for each DE site in a Project	New DE site
	DE description	Design Exception Request Form	New DE site
	Design criteria	Design Exception Request Form	New DE site
Project Information	Project description	Design Exception Request Form	New DE site
	County	Design Exception Request Form	New DE site
	Link to DE report	Needs to be created	New DE site
	Project start date	GDOT GeoPI	New DE site
	Project completion date	GDOT GeoPI	Built DE site
Spatial Information	Coordinates of DE boundaries and 0–0.25-mile and 0.25–0.75-mile buffers	Generated in ArcGIS®	New DE site
	Boundary of analysis	Generated in ArcGIS®	New DE site
Review Information	Date first eligible for review	To be populated for three to five years after project completion date	Built DE site
	Review threshold	To be populated based on support data, see flowchart	New DE site
	Monitoring status	To be populated based on analysis	Built DE site
	Review comments	To be populated based on analysis	Built DE site
	Date of last review	To be populated based on analysis	Built DE site

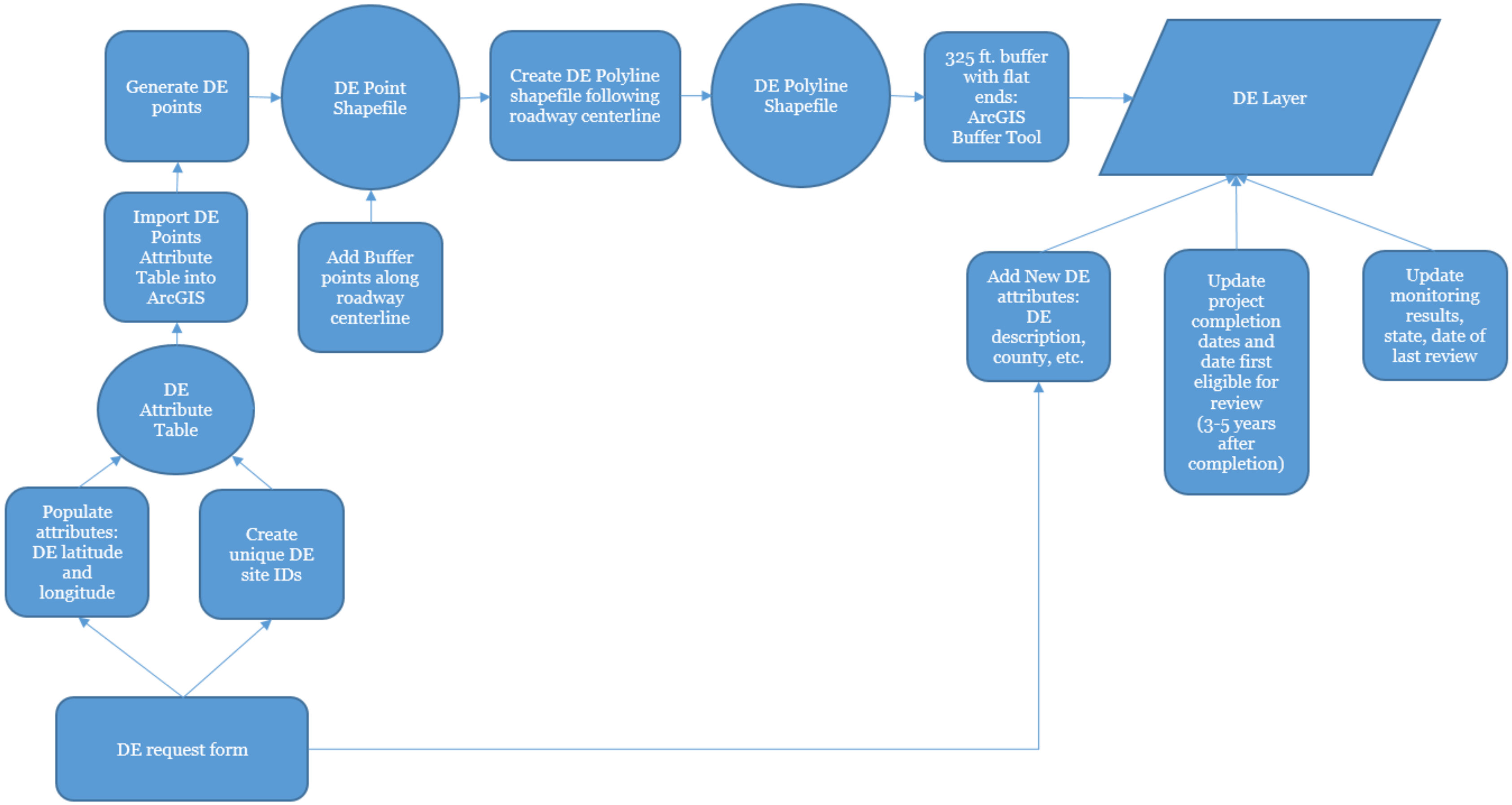

Figure 7: Ongoing Design Exception Monitoring Data Maintenance

The DE attribute table can then be imported into ArcGIS®, the xy points generated, and the data exported to create a shapefile. At this point, the DE point shapefile only contains the location of the DE boundaries. Next, points are added to the shapefile along the roadway centerline to create 0–0.25-mile and 0.25–0.75-mile buffers along the roadway centerline. In the case study, a field was added to the DE point shapefile's attribute table so that the DE points and buffer points could be labeled (i.e. DE, North DE, South DE, West 0–0.25, East 0.25–0.75).

Creating a DE polyline that encompasses the DE sites and centerline buffers is the next step. Multiple polylines are created for DEs that impact multiple roadways, such as DEs that occur at intersections. The attribute table is populated with the unique DE site ID and the DE project ID.

A DE polygon shapefile on the DE Layer is created using the buffer tool in ArcGIS®. The DE polyline is selected and the buffer is set to 325 feet with flat end type. See the case study in Appendix A for an example of the process. The new DE information is added to the attribute table: approved date, DE description, DE project ID, DE criterion, project description, county, link to DE report, review threshold. The review threshold is either the default or the previous three to five years of crash data prior to the DE approval date (Sim, 2012).

Updates should also be made to the DE sites already entered in the database: completion date, date first eligible for review, monitoring status, review comments, date of last review. The date a DE site is first eligible for review is based on the need for one to three years of crash data after the completion of building (Sim, 2012).

Data Assimilation for Annual Evaluation

Two sets of support data are required for annual evaluation: crash data and traffic data. These two types of data will serve as support GIS layers upon which the DE GIS layer will be overlaid.

Crash Data GIS Layer

Ideally, crash data should be spatially identified by latitude and longitude. In addition, the data should contain sufficient information about the crashes, including date, time, lighting, roadway surface condition, accident number, manner of collision, crash severity, pedestrian and bicyclist involvement, etc. Table 5 summarizes the desired attributes to be included in the crash data GIS layer.

The crash data for the case study discussed in Appendix A was gathered in a time-intensive process by downloading crash data by person and crash data by accident for the entirety of the roadway(s) associated with the DE site, using all spelling variations and names for the roadway. The *Crash data by person* table was joined with the *Crash data by accident* table in ArcGIS® 10.2. Points were generated for the entries that included latitude and longitude. The crashes that fell within the DE site buffers were selected and assigned their appropriate unique DE site ID and DE project ID.

The proposed DE monitoring program assumes that the agency has access to crash data as a database with latitude and longitude for many of the entries or as a GIS layer. As with the DE site boundaries, having accurate latitude and longitude for the crash sites creates a more efficient and accurate process. Crash data are required for three to five years before the DE is approved and one to three years after the DE is built (Sim, 2012). In the case study analysis, the researchers noted that crash data were not available in the Georgia Accident Reporting System (GEARS) for the years before 2005. If a DE site has no crashes in the analysis area, then the DE site does not proceed to further analysis. The analyst updates the site information and notes if the evaluation period has expired. The DE site is analyzed the next year for crash data unless the site has been reviewed for three years, in which case the DE site is reclassified as inactive and a review does not occur the next year.

Table 5: Crash Data GIS Layer: Desired Attributes

Data Type	Attribute	Data Source
Crash Data by Incident	Accident Number	Veh Analysis 4 in GEARS
	Date	
	Time	
	County	
	Fatalities	
	Manner of Collision	
	Location of Impact	
	First Harmful Event	
	Light	
	Surface	
	Latitude	
	Longitude	
	Contributing Factors	
Crash Data by Person	Injury type (not injured, killed, serious, visible, complaint, blank)	Veh Analysis 6 in GEARS
Design Exception	DE Unique ID	Generated for each DE site
	DE Project ID	DE Request Form

Traffic Data GIS Layer

The traffic data GIS layer consists of information contained in GDOT's RC Link layer and average annual daily traffic (AADT) for each year under review. This information is required to satisfy the data inputs specified in the HSM.

Table 6 provides more detail on the data required in the traffic data GIS layer. The researchers manually gathered AADT for the case study through GDOT's Traffic Counts site, Geocounts. Manually collecting AADT would be too time consuming for a comprehensive DE monitoring program. However, a script can be written that would extract AADT for the years of analysis based on the count station ID. Analysis requires AADT for three to five years before the DE approved date and one to three years after the DE build is complete. The AADT data should be entered into the RC Link layer attribute table in the case study by creating new fields for the years of analysis and entering the data links within the DE site buffer.

Table 6: Traffic Data GIS Layer: Desired Attributes

Data Type	Attribute	Data Source
Roadway Characteristics	Number of Through Lanes	RC Link layer
	Urban or Rural	
	Section Length	
Traffic Data	AADT	GDOT Traffic Counts: Geocounts

Step Two: Database for Current Year Evaluation

In addition to the GIS updates to the database described above, several additional steps may be necessary prior to the beginning of the annual evaluation process. As shown in the figure below, the annual database may need to be updated to account for changes in the base data (e.g., Crash Data) to be used in the evaluation. Specifically, there will be a need to perform the following:

1. Ensure that the Scripts necessary to retrieve the crash data are up-to-date to reflect any changes in the underlying crash database during the previous twelve months.
2. Ensure that the links to both the historical (accurate for the individual years of analysis) and the current (previous year) information from the RC Link layer are available and linked to the DE GIS layer
3. Ensure that all new DE have been incorporated into the monitoring program and that all expiring design exceptions have been classified as inactive.
4. Update the safety performance functions (SPFs) and crash modification factors (CMFs) to the most current versions unless otherwise determined.
5. Ensure that the necessary DE request documentation has been linked to the new DE polygons.

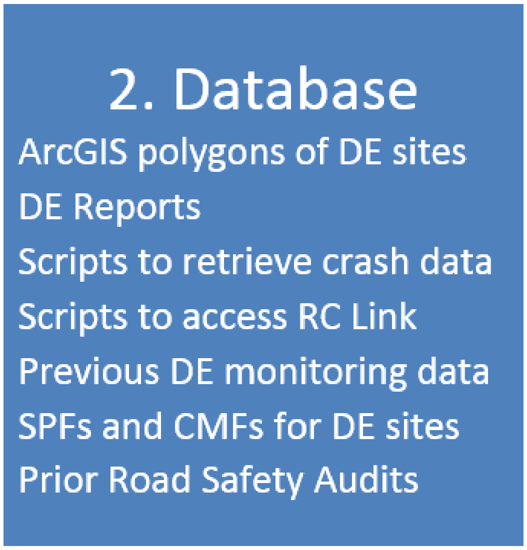

Figure 8: DE Monitoring Program Database

Step Three: Initiate Design Exception Review

In this step, analysts focus on determining if there were any crashes at the DE site for three years before build and the current year of analysis. Any DE site with crashes in the study years proceeds to the *Initial Screening*. If there are no crashes during the study period, then no more analysis is warranted for the current year. The analyst would update the date of most recent review and review comments in the database. The same process repeats the next year unless the site has been retained for three years. If the DE site does not exceed the screening thresholds in the *Initiation of Design Exception Review* section for three years in a row, then the DE is reclassified as inactive and a review is not necessary the next year.

The evaluation process consists of three main steps: (1) *Initial Screening*, which determines if there is an increase in the number and severity of total crashes at a DE site; (2) *Candidate Design Exception Screen*, which analyzes if there is an increase in the number and severity of crashes potentially associated with the DE type; and (3) *Full Review* to determine if any crashes are potentially associated with the DE type by analyzing crash reports and if the effect exceeds the predetermined threshold. This process comprises Steps Four through Six of the proposed DE monitoring program

Step Four: Initial Screen

Initial Screen begins by analyzing the crash table to determine if a DE site has any fatality or serious injury crashes during the current year. DE sites that meet this criterion are prioritized and moved to the *Candidate Design Exception Screen* for further screening. If the DE site does not have any crashes with fatalities or serious injuries, then the crashes are analyzed using the following criteria:

1. Do total crashes for current year of analysis exceed the expected number of crashes (SPF)?
2. Including the current year, does the proportion of non-severe injury crashes increase after the project was built as compared to before the project was built?

Analysis is conducted to determine if crashes at the DE site exceed the first screening threshold by comparing actual crashes for the current year of study to predicted crashes for the current year of study. Analysis of the screen threshold compares the current-year crash frequency to the predicted crash frequency based on the HSM method. Due to lack of local data (Rodgers, Shaw, & Wilson, 2015), the researchers simply calculate the predicted crash frequency using the SPF for the site's facility type, according to the HSM. To be conservative, the researchers streamlined the initial screening process to utilize only the SPF for roadway segments. This is based on the assumption that the presence of intersections will add to the predicted number of crashes (SPF). Appendix D includes the SPF formulas that should be used for different facility types, and the methodology is further described in the case study in Appendix A.

If the first criterion is not met, the monitoring program further assesses the total crashes to determine if the proportion of injury crashes has increased as compared to crashes with property damage only (PDO). This analysis is carried out using the hypothesis test for crash frequency and the hypothesis test for crash severity described in Appendix B: Theoretical Foundation.

For each project, if the DE site exceeds any of the screening thresholds listed previously, the DE site is moved forward for further investigation under the *Candidate Design Exception Screen* process. Otherwise, no more investigation is warranted for the current year. The analyst would update the date of most recent review and review comments in the database. The same process repeats the next year unless the site has been retained for three years. If the DE site does not exceed the screening thresholds in the section for three years in a row, then the DE is reclassified as inactive and a review is not necessary the next year.

Step Five: Candidate Design Exception Screen

DE sites that met one of the criteria in the *Initial Screen* are then analyzed under the *Candidate Design Exception Screen*. The first step of the *Candidate Design Exception Screen* is to analyze the crash table for any crashes with severe injuries or fatalities. If there are any fatalities or serious injuries, then the DE site moves to *Full Review*. If the DE site does not have any fatalities or serious injury crashes, then the analyst would look at the following criteria for the *Candidate Design Exception Screen*:

1. Is there an increase in the frequency of total crashes that could be associated with the DE type?
2. Is there an increase in the proportion of non-severe injury crashes that could be associated with the DE type?

The analyst applies the criteria in the table in Appendix E to label crashes as potentially associated with a DE type. These crashes are then pulled out for analysis in the *Candidate Design Exception Screen*.

The hypothesis test focusing on the potential increase in frequency of all potentially DE-associated crashes after a project is formulated as $H_0: \gamma \leq 1$ versus $H_a: \gamma > 1$. The following recommendations by Aban et al. (2009), a likelihood-based inference method known as the score test, was adopted (Cox & Hinkley, 1974). Aban et al. (2009) derived the test statistic as,

$$Z_S = \frac{(\bar{y} - \hat{\mu}_0)}{(\hat{\theta}_0 + \hat{\mu}_0)} \sqrt{\frac{n\hat{\theta}_0[m(\hat{\theta}_0 + \hat{\mu}_0) + n(\hat{\theta}_0 + \hat{\mu}_0)]}{m\hat{\mu}_0}}$$

where $\hat{\mu}_0$ and $\hat{\theta}_0$ solve the system of equations,

$$\begin{cases} \hat{\mu}_0 = \frac{\sqrt{[m(\bar{x}-\hat{\theta}_0)+n(\bar{y}-\hat{\theta}_0)]^2+4\hat{\theta}_0(m+n)(m\bar{x}+n\bar{y})}}{2(m+n)} + \frac{m(\bar{x}-\hat{\theta}_0)+n(\bar{y}-\hat{\theta}_0)}{2(m+n)} \\ 0 = -(m+n)[\Psi(\hat{\theta}_0) - 1] + \sum_{i=1}^{m} \Psi(x_i + \hat{\theta}_0) + \sum_{j=1}^{n} \Psi(y_j + \hat{\theta}_0) + m \ln(\frac{\hat{\theta}_0}{\hat{\theta}_0 + \hat{\mu}_0}) \end{cases},$$

and $\Psi(\cdot)$ denotes the digamma function.

Under the conditions defined above, an approximate α-level test for $H_0: \gamma \leq 1$ versus $H_a: \gamma > 1$ rejects H_0 when $z_S > z_\alpha$, where z_α denotes the $(1-\alpha)100th$ percentile of a standard normal distribution. Appendix F includes the code that can be run in “R” statistical software (a widely available public domain statistical software package) to complete the hypothesis test. The theoretical foundation for this method is provided in the Theoretical Foundations in Appendix B.

The final screening criterion under the *Candidate Design Exception Screen* is a hypothesis test to determine if there was an increase in crash severity for the crashes potentially associated with the DE type by comparing PDO crashes to injury crashes for only crashes at the DE site that potentially were associated with the DE type. A hypothesis test of all PDO versus injury crashes was conducted earlier in the *Initial Screen* section. The hypothesis test on crash severity is conducted using the formula below and by assuming p_1 is the proportion of injuries and fatalities before the project, and p_2 is the proportion of injuries and fatalities after the project. The hypothesis test is $H_0: p_2 \leq p_1$ versus $H_a: p_2 > p_1$.

The Z test statistic is used as shown below:

$$Z = \frac{\widehat{p_1} - \widehat{p_2}}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})}}$$

where $\hat{p}$ is the combined before and after proportion of injuries and fatalities, and

n_1 and n_2 are the number of crashes before and after the project, respectively.

As such, an α-level test rejects the null hypothesis when $|Z| > z_\alpha$, where z_α denotes the $(1-\alpha)100th$ percentile of a standard normal distribution. z_α = 1.645.

If there are crashes at a DE site that exceed the screening rule, then the DE site moves to *Full Review*. If the DE site does not exceed the screening rule, then the analyst updates the DE Layer and also determines if the evaluation period has expired. If the evaluation period of three years has not expired, then the DE site will be reviewed in the next year; however, if the evaluation period has expired, then the analyst should reclassify the DE site as inactive and the site will not be reviewed the next year.

Step Six: Full Review

If a DE site exceeds the *Candidate Design Exception Screen* rules, then the DE site is analyzed in the *Full Review* section. Under the *Full Review* screen, crashes at the DE site are analyzed using the following steps: (1) sample total crashes for the current year of analysis; (2) gather and analyze crash reports for sampled crashes to detect at least one crash potentially associated with DE type; (3) sample crashes to determine if any detected effects exceed a threshold limit; and (4) perform a recommended *Road Safety Audit* if the effect threshold is exceeded.

Crashes can be caused by multiple factors, sometimes singly but often in combination: vehicle, driver, roadway, and environmental factors (Spainhour, Brill, Sobanjo, Wekezer, & Mtenga, 2005). The primary concerns of this analysis are the roadway factors and the impact of

DE type on crash type. It is difficult to determine which roadway factors contributed to a crash; however, the roadway factors that did not contribute to a crash can be more easily determined. This is a more conservative analysis as some crashes in which roadway characteristics were not causative factors for the crash may pass on to *Full Review* and it is less likely that crashes with roadway characteristics that are causative factors for the crash will not pass to *Full Review*.

First, crashes are sampled for a 95% confidence of finding at least one crash related to the DE type. If there are 20 or more crashes, then a hypergeometric distribution is used to determine the necessary number of crash samples. If there are less than 20 crashes at the DE site, then all of the crashes are analyzed. For the hypergeometric distribution sampling, population size for all current-year crashes at the DE site is denoted as N and the number of crashes associated with the DE is denoted as K.

$$P(X = 0) \equiv \frac{\binom{K}{0}\binom{N-K}{n-0}}{\binom{N}{n}} \leq 0.05$$

The minimum n can be found using a standard software, such as the HYGEOM.DIST function in Microsoft Excel®. See Appendix A for application of the *Full Review* in the case study analysis.

If no crashes meet the criteria, then the analyst updates the DE Layer and notes if the evaluation period has expired. If at least one crash meets the criteria, then all crashes at the DE site are sampled to determine if the effect exceeds the threshold limit that GDOT accepts for a DE. If they exceed the effect threshold, then the DE site is moved to a *Road Safety Audit* and the DE Layer is updated to reflect this recommendation. If the crash records do not exceed the threshold, the analyst updates the DE Layer and notes if the evaluation period has expired.

Step Seven: Road Safety Audit

Any DE site that is shown to exceed the threshold conditions in the *Full Review* screening will be recommended for a *Road Safety Audit* using the current standard approaches from the GDOT Office of Safety and corresponding federal guidance.

Continuous Update and Review Process

The update and review process includes updating the DE Layer and updating the DE monitoring report. The DE Layer will have four data fields for updates:

1. Date of Last Review
2. Final Stage of Last Review, as numbered in the section
3. Comments, including the results of the most recent evaluation
4. Date of Expiration, which defaults to three years after project completion date, but will be extended for one year each time a site is moved beyond stage one of the Evaluation Process. Projects past their date of expiration are marked as inactive.

Conclusions and Recommendations

The primary objective of this research program was to develop an in-service monitoring program for design exceptions that was implementable and cost-effective. The design of such a program is challenging as there is a fundamental tradeoff between the rigor by which the review can be performed and the resource demands necessary for its implementation. In the proposed program the researchers achieved a good balance between making maximum use of the data that are currently available while minimizing additional data collection and quality assurance/quality control demands.

An important step in minimizing these resource requirements is to ensure that the information necessary for conducting these future audits is available early in the design exception review process. In this project, significant resources were expended in determining exact Design Exception locations, project extents and other relevant parameters necessary to conduct the analysis. The proposed changes to the design exception request process are both relatively minor and aimed at significantly reducing the time necessary to acquire this information in the future. These proposed changes will pay important dividends in reducing future monitoring costs. In particular, these process changes should be implemented as soon as possible.

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Appendix A: Case Study Application of the Proposed Program

Case Study Overview

A case study of the proposed DE monitoring program was conducted with the goal of both demonstrating its feasibility as well as evaluating the strengths and weaknesses of the proposed approach. For this study, sites with a DE for horizontal alignment were considered as they were the DE type with the highest number of sites meeting the criteria. The selection criteria required that DE sites used in the analysis had:

- an approval date from 2008 to 2014,
- a completion date from 2009 to 2014,
- a DE report accessible at the time of research, and
- design plans accessible in TransPI at the time of research.

From the 23 horizontal alignment DEs that met these criteria and were included in the DE Monitoring Data Maintenance section, two DE request forms with a total of six DE sites were chosen for this DE monitoring program case study. These selected sites underwent the complete DE monitoring program analysis, including: (1) ongoing DE monitoring database maintenance, (2) DE monitoring database quality assurance for the candidate sites, (3) initial site review to determine if there were any crashes at the DE site(s) during the study period, (4) *Initial Screen* (5) *Candidate Design Exception Screen*, and (6) *Full Review*. The seventh step in the DE Monitoring Program, *Road Safety Audit*, was not recommended for the DE sites in the case study as they did not meet the threshold limit set in the *Full Review*.

The selected horizontal alignment DE sites were 751300-1, 751300-2, 751300-3, 0004405_1, 0004405_2, and 0004405_3. The full progression of the case study analyses is illustrated in Figure 9. The analyses of DE sites 751300-1 and 751300-2 were terminated at Step Three (Initiate Design Exception Review) as neither site had any identified crashes for the study period (based on latitude and longitude information). Analyses of DE sites 0004405_2 and 0004405_3 also did not progress past Step Three as the roadways impacted by the overlapping DE buffers, Olive Springs Road and Sandtown Road, did not have any post-construction crashes. The remaining sites (DE sites 751300-3 and 0004405_1) had identified crashes based on latitude and longitude information during the study period and thus progressed to the *Initial Screen* process.

One of these locations (DE 0004405_1) did not progress past the *Initial Screen* as the current-year crashes after the DE site was built did not exceed the predicted crash frequency. When analyzed under the *Initial Screen* step, DE 751300-3 had higher actual crashes than expected crashes, so was moved to the *Candidate Design Exception Screen* (Step Five). While DE 751300-3 did not meet the criteria for passing beyond this step (i.e., an increase in frequency or severity of crashes potentially associated with the DE type), the DE site was analyzed by the researchers under Step Six, *Full Review*, for purposes of the case study. The following sections describe each of the individual steps of the case study analyses in more detail.

Selection of Design Exception Sites for Case Study

The DE database created for this research included information regarding 663 DE sites. As mentioned previously, for purposes of the case study the database was queried to identify all DE with an approval date between 2008 and 2014 and a construction end date between 2009 and 2014 for which both a DE report and design plans were available at the time of research. The query found that 89 DE projects met these criteria. See Figure 10 for the number of DEs that met each criterion. The distribution of specific DE types associated with these sites is provided in Table 7. As the horizontal alignment DE type provided the largest number of potential locations, the research team selected those sites for analysis in the case study. A survey of state DOTs by Mason Jr. and Mahoney (2003) also found that horizontal alignment was the most frequent DE type.

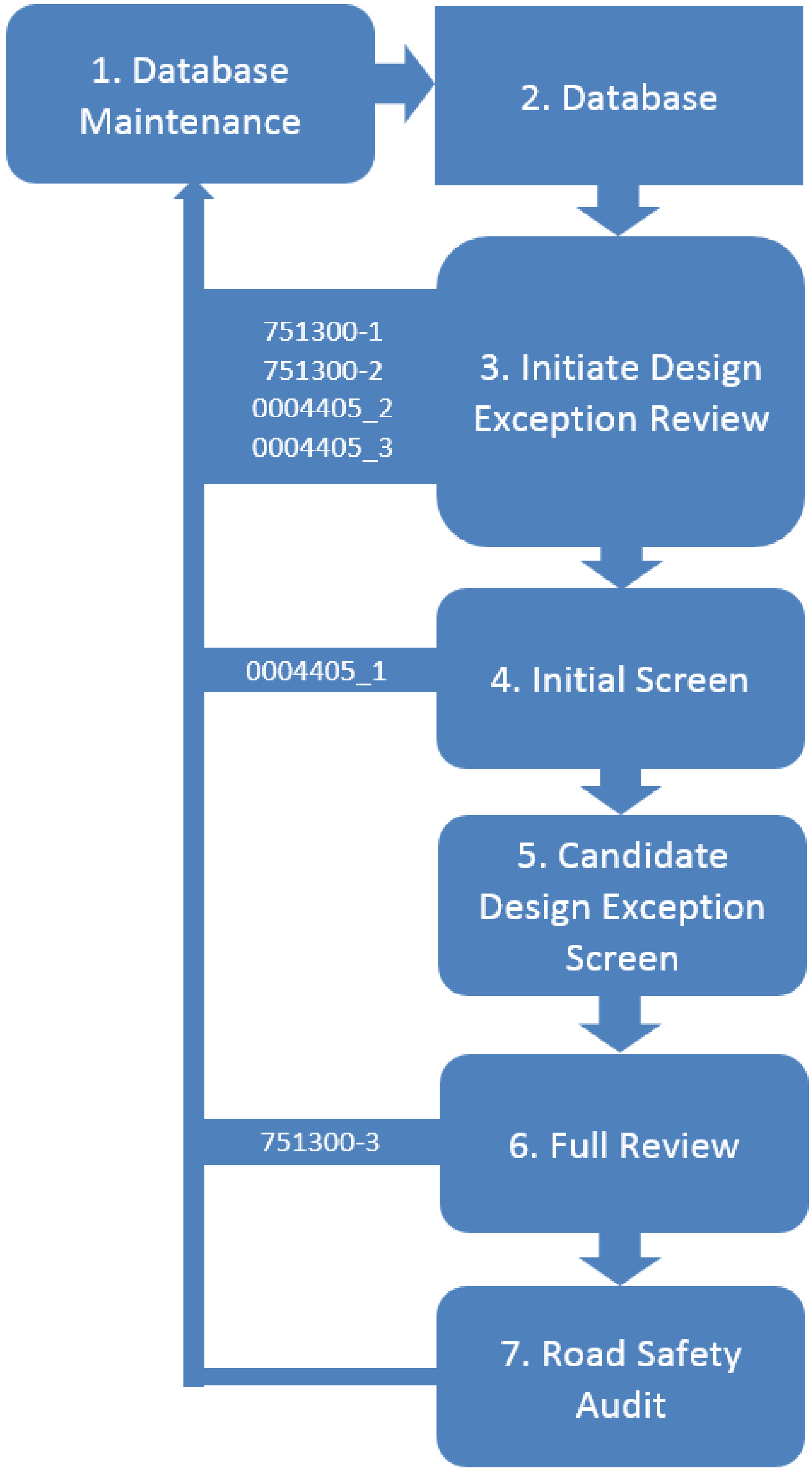


Figure 9: Horizontal Alignment DE Types Analyzed in Case Study

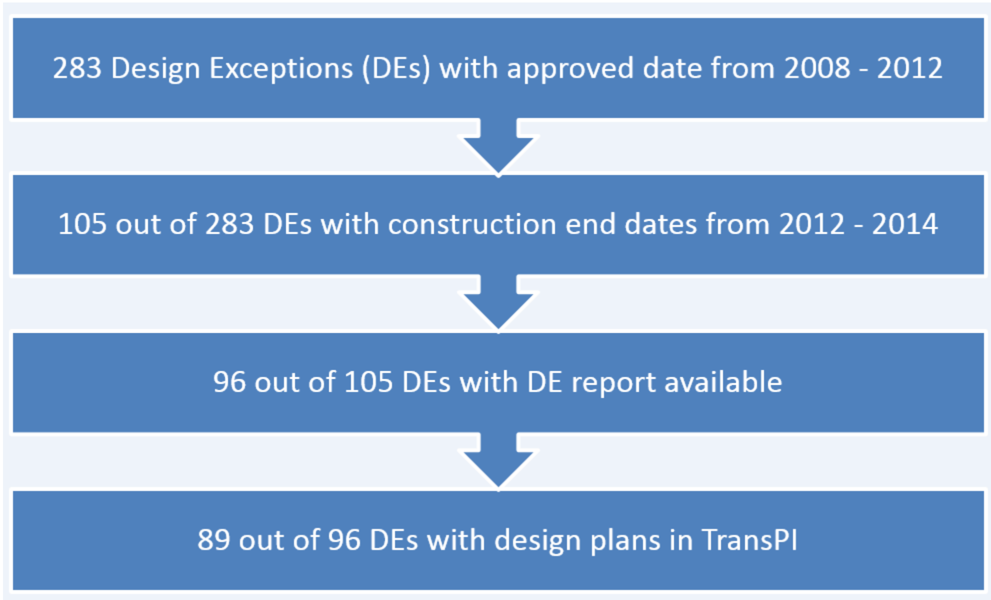


Figure 10: Selection of Design Exceptions Based on Criteria

Table 7: Number of DE Sites that Meet Criteria by DE Type

DE Type	# DE Sites
Horizontal Alignment	23
Shoulder Width	19
Vertical Alignment	12
Horizontal Clearance	11
Lane Width	9
Superelevation	7
Stopping Sight Distance	3
Grade	3
Bridge Width	1
Design Speed	1
Cross Slope	0
Vertical Clearance	0
Structural Capacity	0

Figure 11 illustrates the locations of the projects having a horizontal alignment DE that were included in the case study. The project ID numbers shown in the figure are those that were assigned when the initial DE request form was submitted for approval. These 15 projects represent a total of 23 DE sites since one DE project request form may include multiple DE types and/or sites. Table 8 provides a list of the projects and their associated horizontal alignment DE ID numbers.

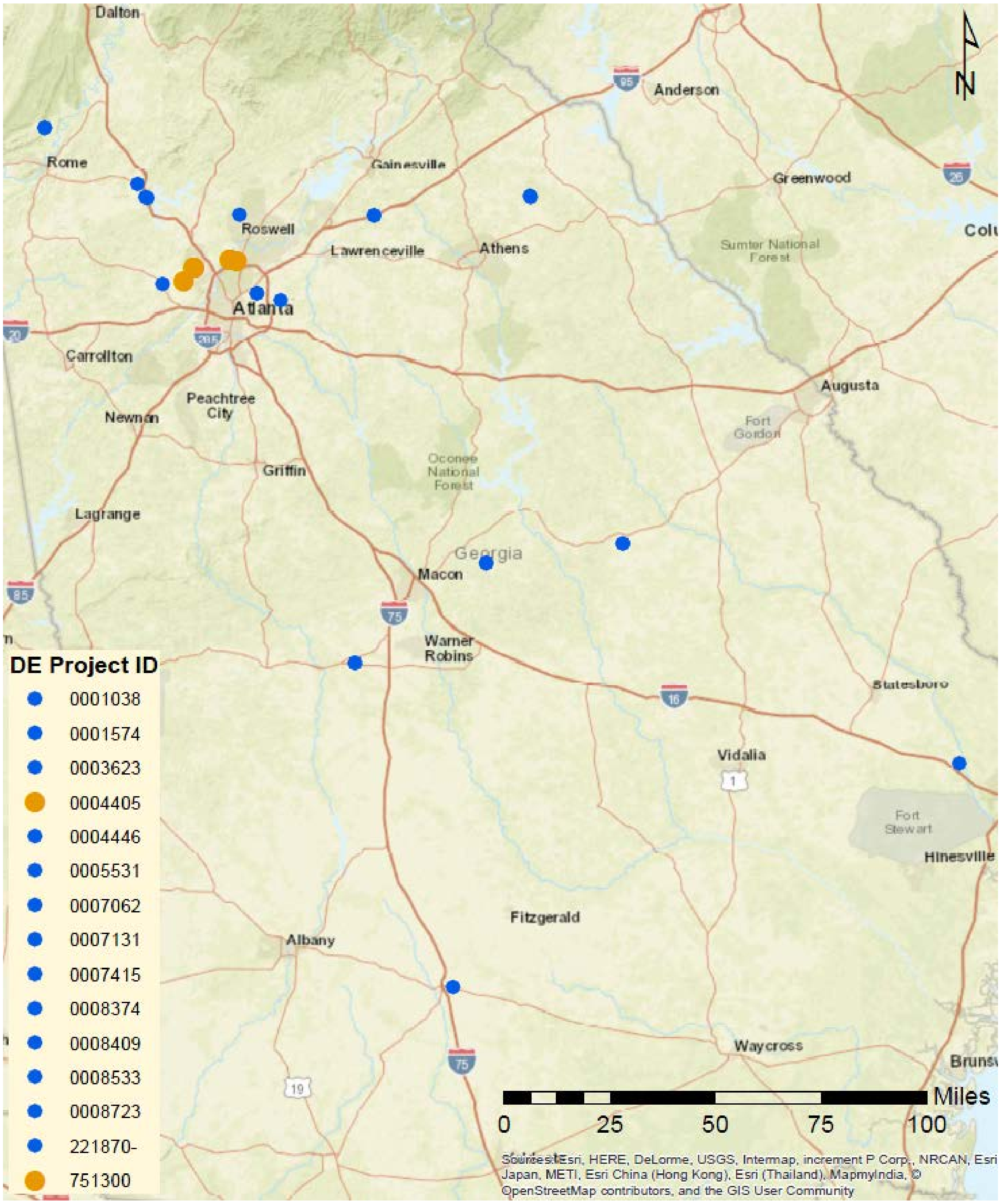


Figure 11: Horizontal Alignment DE Projects

Table 8: Horizontal Alignment DE Project IDs and DE Site IDs

DE Project ID	DE Site ID
0001038	0001038
0001574	0001574_1
	0001574_2
	0001574_3
0003623	0003623_1
	0003623_2
0004405	0004405_3
	0004405_2
	0004405_1
0004446	0004446
0005531	0005531
0007062	0007062
0007131	0007131
0007415	0007415_1
	0007415_2
0008374	0008374
0008409	0008409
0008533	0008533
0008723	0008723
221870-	221870-
751300-	751300-1
	751300-2
	751300-3

Maintenance and Data

Step One: Case Study Design Exception Monitoring Data Maintenance

Creating the Design Exception GIS Layer

A DE polygon shapefile was created in ArcGIS® 10.2 and is referred to as the DE Layer. The polygon encompasses the DE site (point or segment), 0–0.25-mile and 0.25–0.75-mile buffers along the roadway centerline, and a 325-foot buffer out from the roadway centerline in both directions. The attribute table includes DE information, project information, spatial information, and review information. Table 9 includes a comprehensive list of the attribute table elements. The process of building the DE Layer began with locating the DE site in ArcGIS®

using the DE request forms, marking the DE site and centerline buffers in a DE point layer, creating a DE polyline layer, and finally creating the DE Layer by using the buffer tool in ArcGIS®. The DE Layer attribute table was populated using DE request forms, TransPI, and the analysis results described later.

Table 9: Data Sources Used and Created for the DE Monitoring Data Maintenance

Data Type	Data	Source	Agency	Field(s)
Shapefile/ArcGIS®	RC Network	GDOT	GDOT	RCLINK, BEG_MEASUR, END_MEASUR, INTERSECT_
PDF	Design Exception Requests	GDOT	GDOT	Description of design exception location
Table/Excel	Design Exception Database	GDOT and additional data added by Georgia Tech	GDOT and Georgia Tech	DE Proj ID, DE ID, Exception Type, Approve Date, Mile Point End, Mile Point Begin, Comment, Design Plans in TransPI, DE report available, Current Completion Date
PDF	Design Plans	TransPI	GDOT	Location of design exception segments
Shapefile/ArcGIS®	Design Exception Point Shapefile	Created by Georgia Tech	Georgia Tech	Location, DE_ProjID, De_ID
Shapefile/ArcGIS®	Design Exception Polyline Shapefile	Created by Georgia Tech	Georgia Tech	DE_ID, DE_ProjID
Shapefile/ArcGIS®	Design Exception Polygon Shapefile	Created by Georgia Tech	Georgia Tech	DE_ID, DE_ProjID

DE Point Layer

Since latitude and longitude information were not generally available for the existing DE request forms, the research team created the DE point layer through a manual process based on the current DE request forms. From information contained in the request forms, each DE site was located in space using Google Maps® or Google Earth® via intersection street names and other information contained in the request. Once identified in space, each DE site was linked to the GDOT RC Link database using a variety of methods, depending on the data available:

- Select by attributes search in ArcGIS® for RC Link ID and narrowing the geographic area by zooming into the DE mile points (RC Link ID and mile points are included in the DE database for some DEs; however, these data were not always found to be accurate)
- Select by attributes search in ArcGIS® for RC Link ID and visually searching for the DE location using Google Maps as a reference
- Select by attributes search in ArcGIS® for an intersecting street name (pulled from Google Maps) using the "INTERSECT_" field

A DE point layer was created to mark the location of the DE (a single point for an intersection or two points for a segment such as a curve radius), 0–0.25-mile buffers, and 0.25–0.75-mile buffers. Figure 12 and Figure 13 illustrate the DE point layers for DE 0004405_1 and 751300-3, respectively. The points were assigned a location ID, DE project ID, and DE unique ID field in the DE point layer attribute table. As noted previously, some DE projects have multiple DE sites, so the researchers created unique DE site IDs such that the sites could be analyzed individually.

DE sites that were located at intersections such as DE 751300-3 and DE 0004405_1 were relatively easy to locate on the RC Link layer in ArcGIS® using information provided in the DE request forms and information in the DE database; however, DE sites that covered a segment of roadway, such as a curve radius, required the use of design plans to identify their location. Some DE requests included design plans for the DE site, but many did not. If the DE request did not include a design plan, the design plan was located by the researchers in GDOT's TransPI database. In the researchers' experience, this process could take up to an hour to identify the correct design plan and locate the beginning and ending of the DE on the RC Network shapefile. As suggested previously, the use of latitude and longitude to identify the beginning and ending of the DE would significantly streamline this process.

Table 9 lists the data sources used in analysis and data sources created during the case study. The fields listed are only those that were most important to the case study and are not a comprehensive list of the fields for each data source.

The DE point layer includes spatial information, DE project information, and DE site information in the attribute table. The spatial information details the DE site location (e.g., DE, North DE, South DE, West DE, East DE), 0–0.25-mile roadway centerline buffers (ex. North 0–0.25, South 0–0.25, West 0–0.25, East 0–0.25), and 0.25–0.75-mile roadway centerline buffers (ex. North 0.25–0.75, South 0.25–0.57, West 0.25–0.75, East 0.25–0.75). The DE project information contains the DE project ID, while the DE site information lists the unique DE site ID. As mentioned previously, some DE projects in the horizontal alignment sample had multiple DE sites assigned to the same project ID. The DE project ID was modified in the DE database and DE point shapefile to uniquely identify these DE sites (e.g., DE project ID 751300- is associated with these DE sites: DE 751300-1, 751300-2, and DE 751300-3).

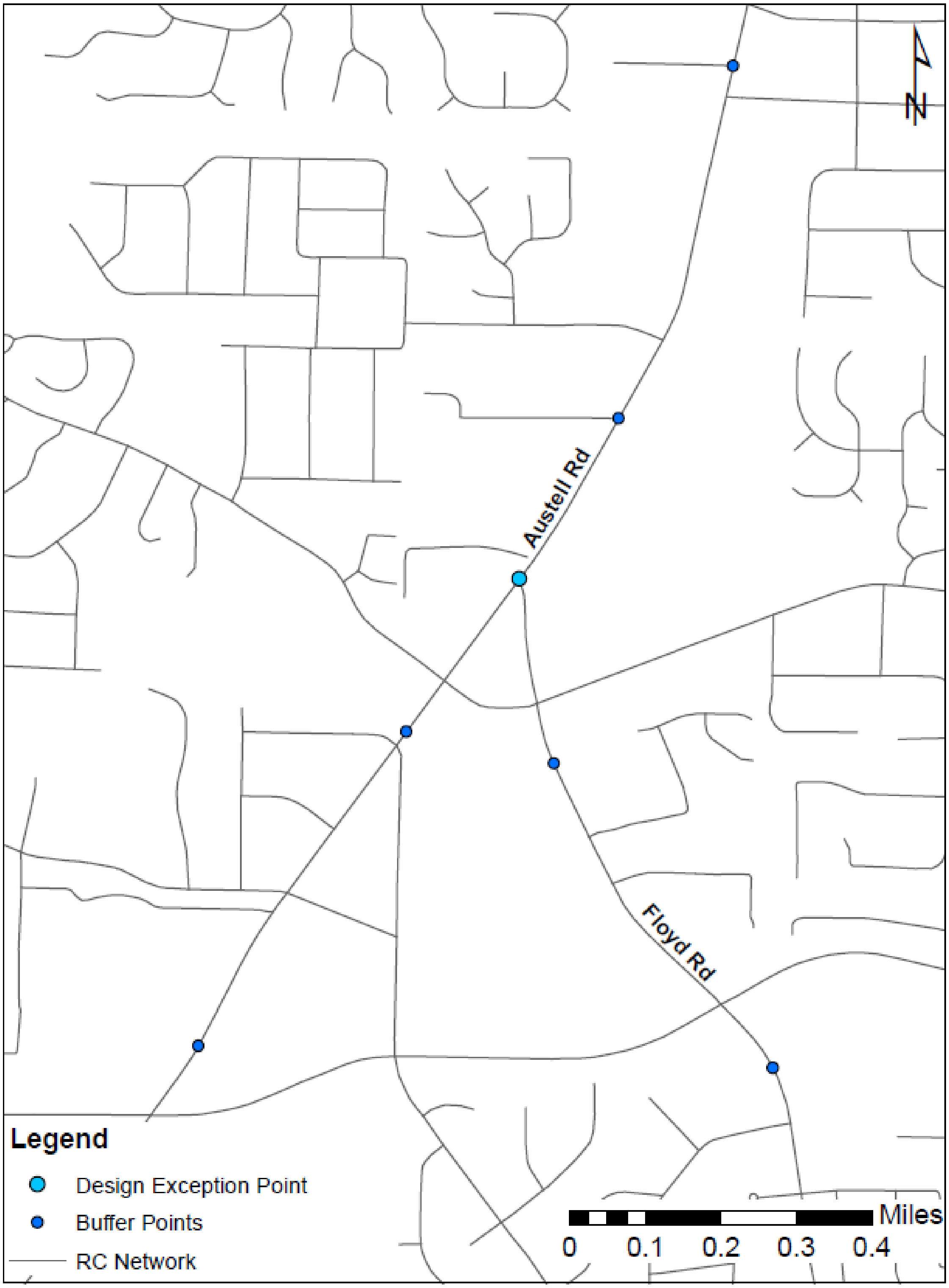


Figure 12: DE 0004405_1 DE Point Layer

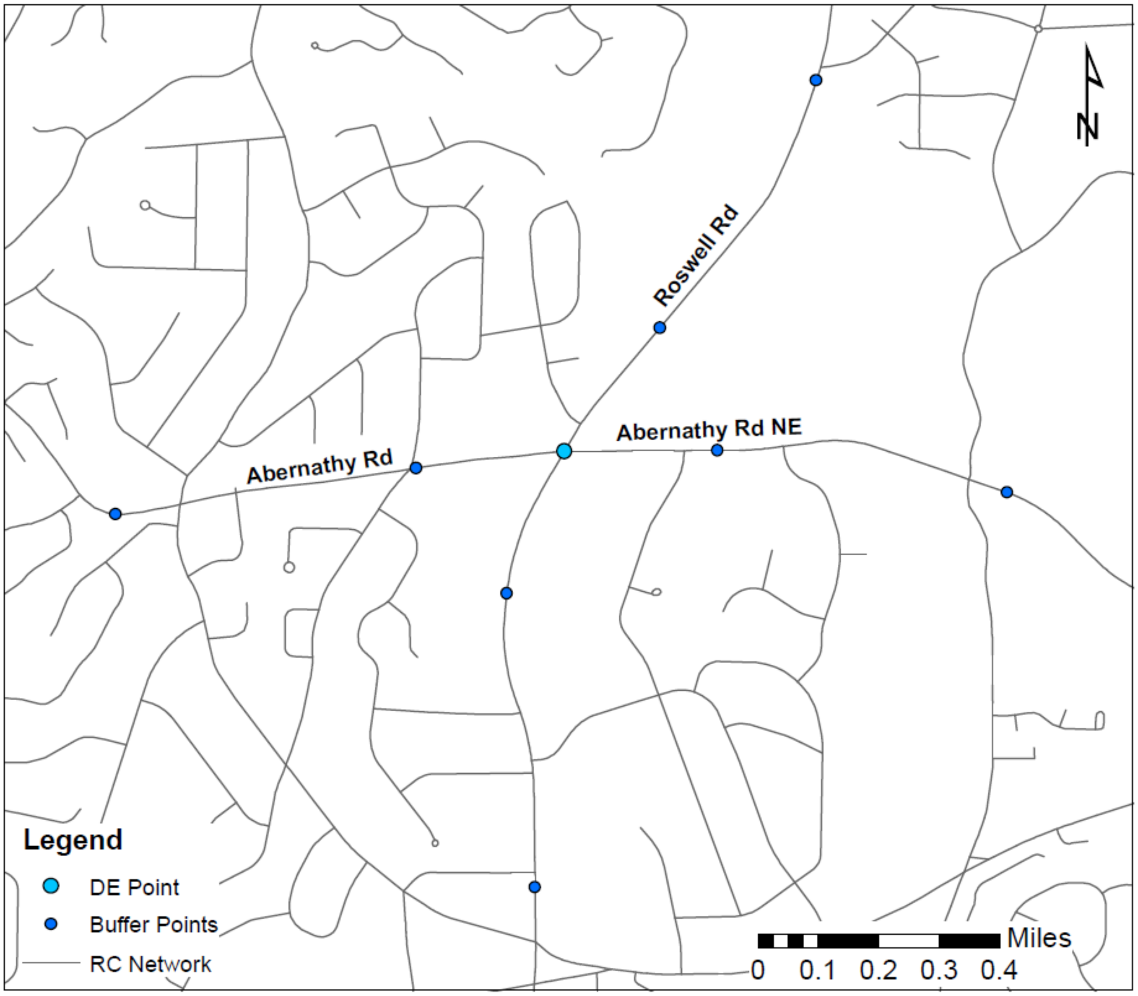


Figure 13: 751300-3 DE Point Layer

DE Polyline Layer

A DE polyline shapefile was created using the ArcGIS® editor tool, with all of the snapping functions selected, that followed the RC Link layer roadway centerline and included the 0–0.25-mile and 0.25–0.75-mile roadway buffers and DE site boundaries. Multiple polylines were created for DE sites that impacted multiple roadways, such as at intersections. The polylines were assigned the DE project ID and the DE unique ID in the DE polyline layer attribute table. Figure 14 and Figure 15 are maps of the DE polyline layer for DE 0004405_1 and 751300-3, respectively.

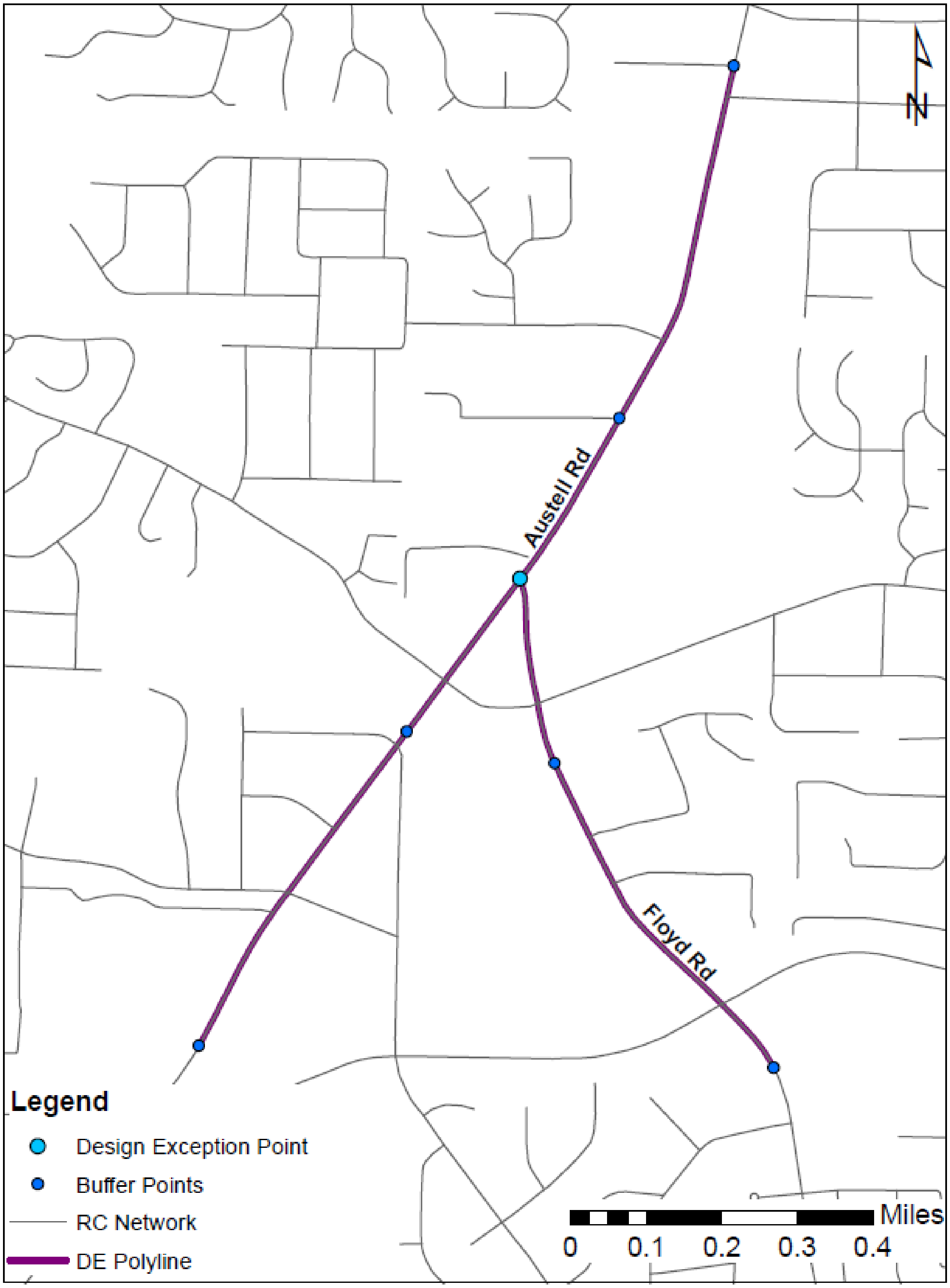


Figure 14: DE 0004405_1 Polyline Layer

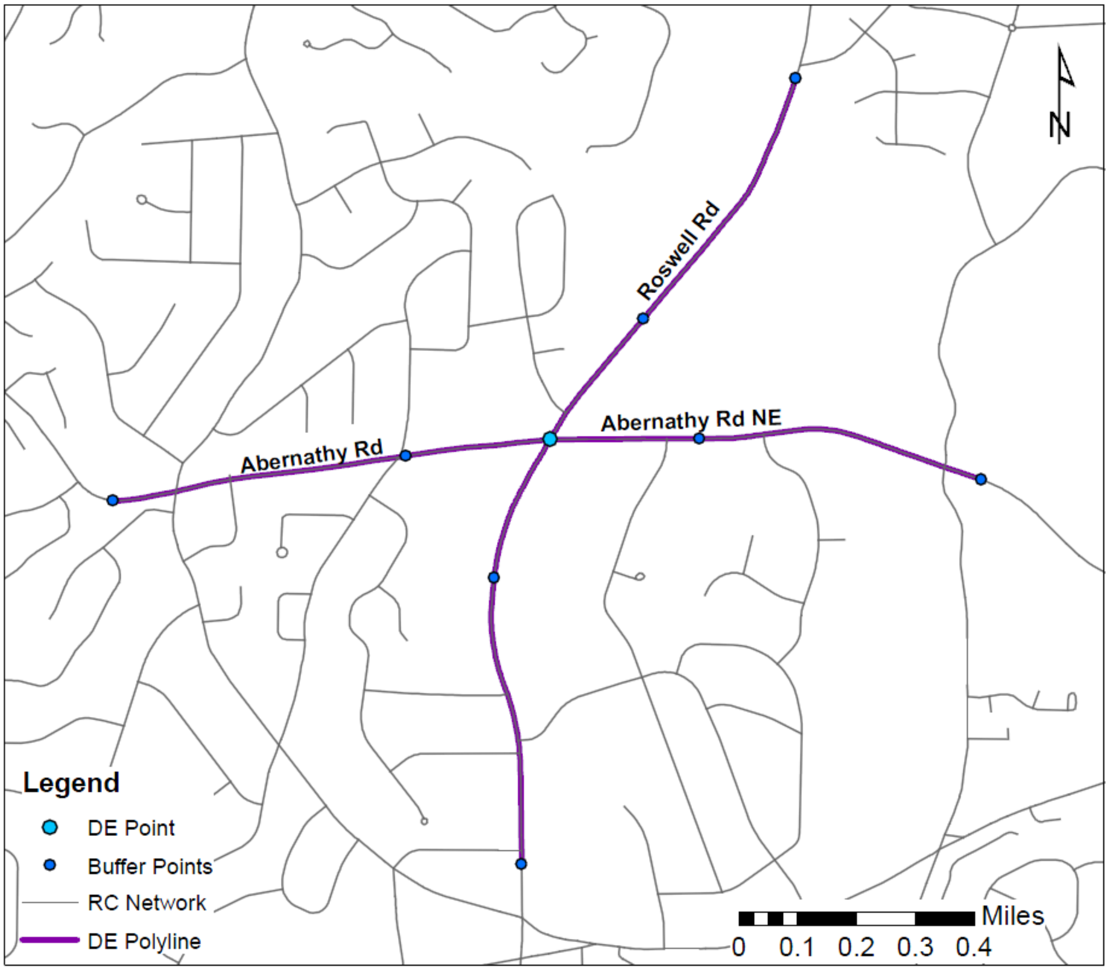


Figure 15: DE 751300-3 Polyline Layer

DE Polygon Layer or DE Layer

A DE polygon was created by using the buffer tool in ArcGIS®. The buffer was set to 325 feet with flat end type. See Figure 16 for the buffer settings. As mentioned previously, some DE sites impact multiple roadways and were assigned multiple lines, which resulted in the creation of polygons that overlap at points such as intersections. The overlapping polygons for the same DE site can be combined using the dissolve tool in ArcGIS®. Figure 17 and Figure 18 are maps of the DE Layer for DE 0004405_1 and 751300-3, respectively.

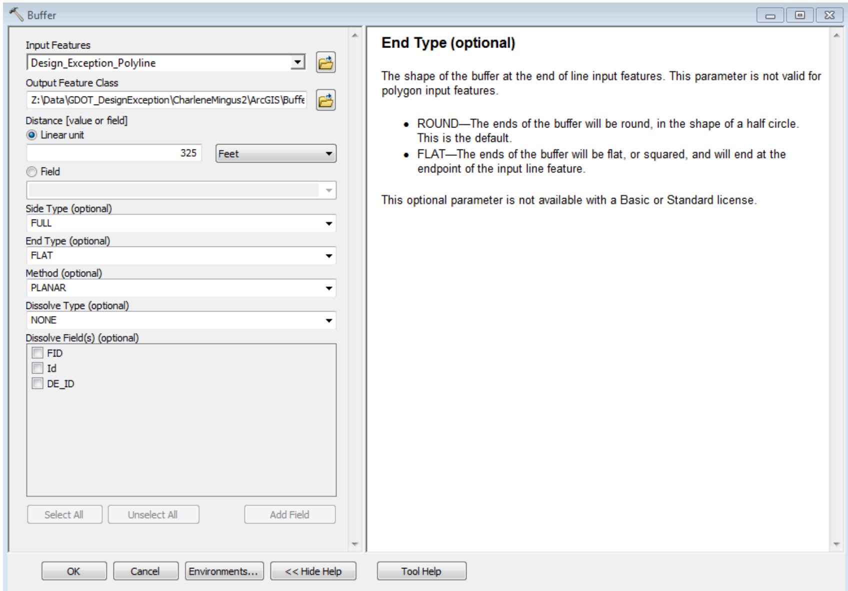


Figure 16: Design Exception Buffer Settings in ArcGIS® 10.2

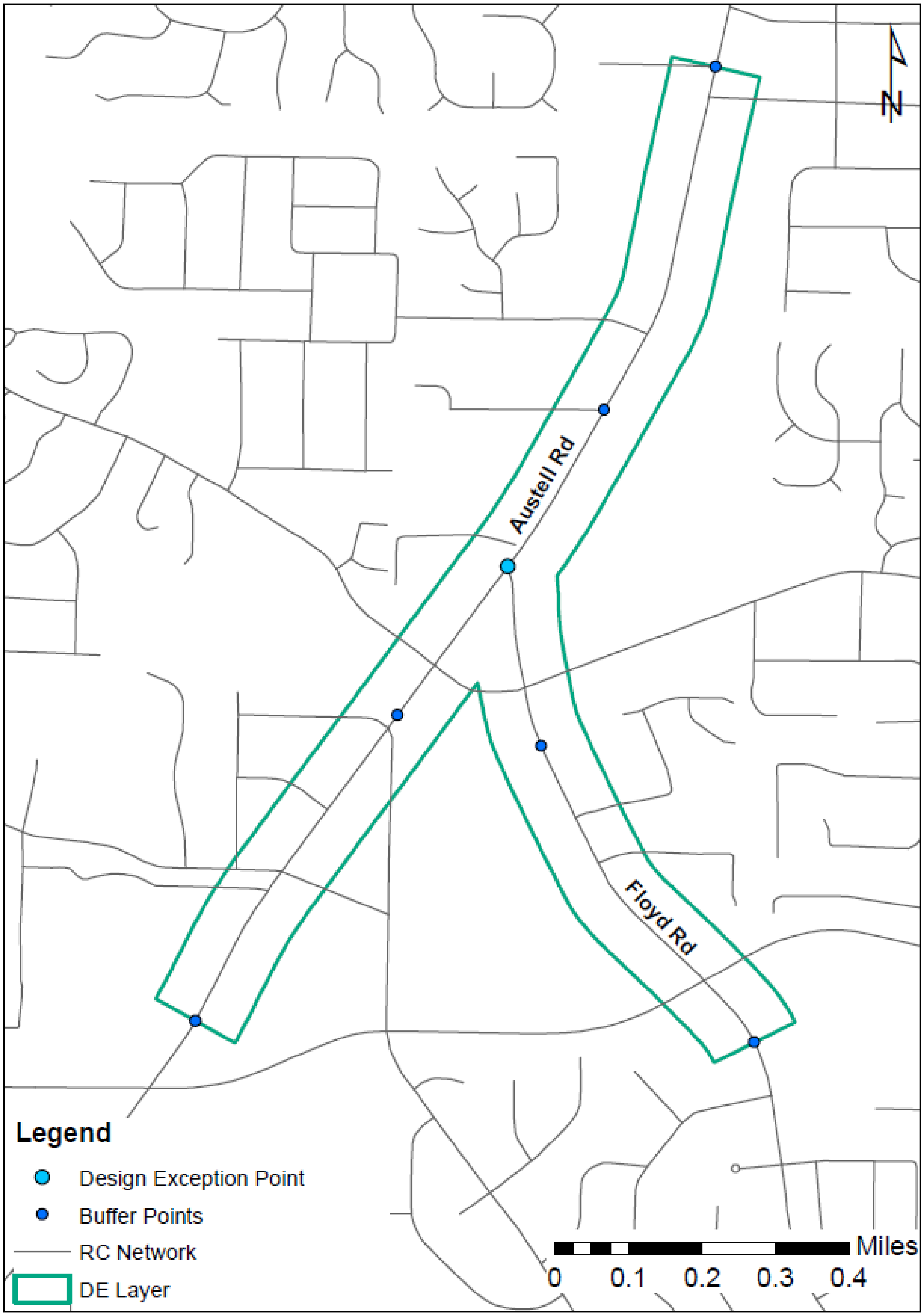


Figure 17: DE 0004405_1 DE Layer

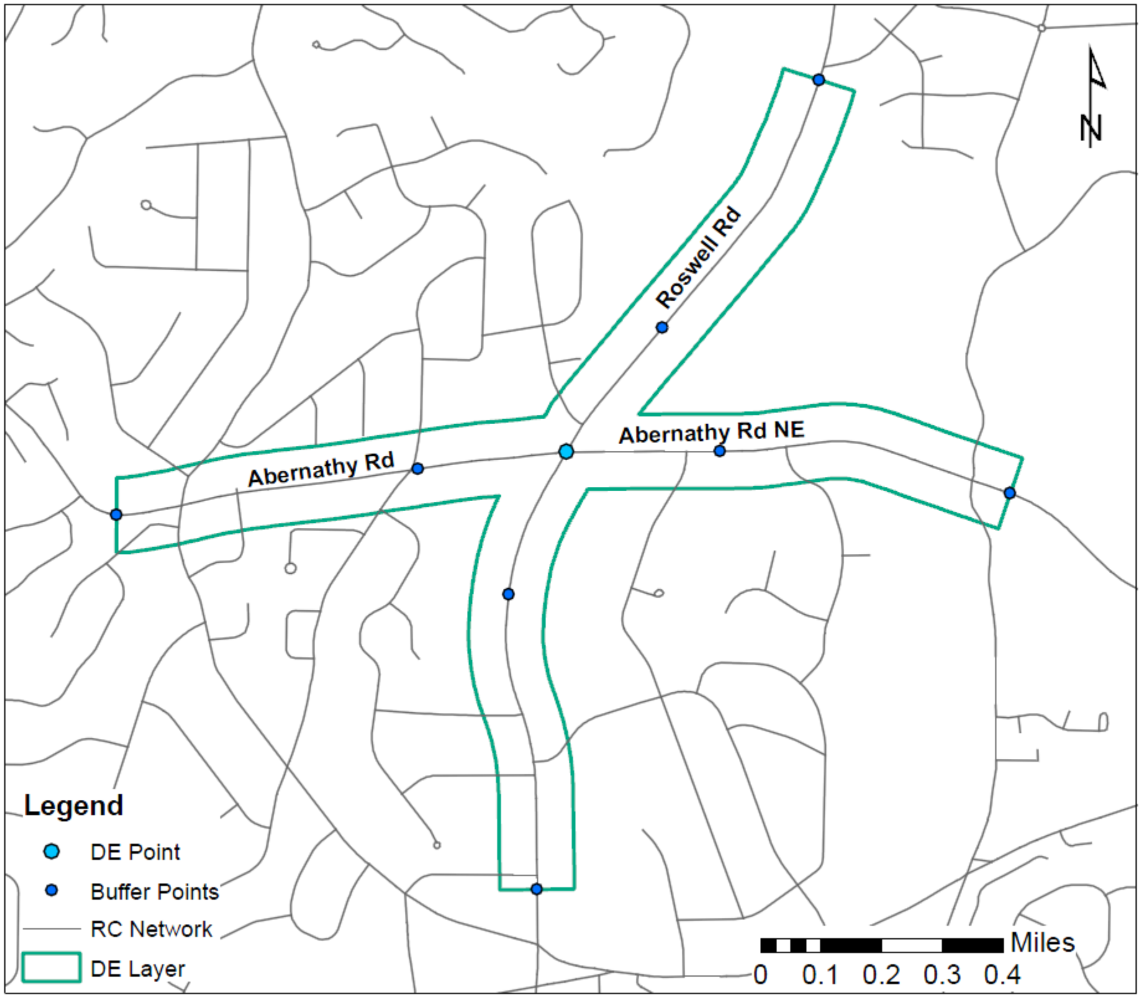


Figure 18: DE 751300-3 DE Layer

Step Two: Case Study Database for Current-Year Evaluation

Crash Data

The researchers assimilated crash data for the six DE sites included in the case study by searching the GDOT GEARS crash database. The advanced search was limited by date (01-01-2002 to 12-31-2014) and roadway name. An extensive list of roadway names was used in the search field, as the same roadway may have crashes classified under abbreviations and alternative road names. Table 10 lists the roadway search terms used for the DE sites 751300-1, 751300-2, and 751300-3, while Table 11 includes the roadway search terms used for the DE sites 0004405_1, 0004405_2, and 0004405_3.

Crash data by incident (Veh Analysis 4 in GEARS) and *Crash data by person* (Veh Analysis 6) query results were downloaded for each roadway search term. *Crash data by incident* included accident number, date, time, county, fatalities, manner of collision, location of impact, first harmful event, light, surface, latitude, longitude, and contributing factors. *Crash data by person* contained many of the same fields but uniquely contained data on injury type (i.e., not injured, killed, serious, visible, complaint, blank). See Table 12 for the fields included in the crash table.

The multiple *Crash data by incident* tables (one for each roadway search term) were combined to create a master *Crash data by incident* table in Microsoft Excel® for each DE location. A similar process was conducted for the *Crash data by person* tables, resulting in a master *Crash data by person* table, as well. An additional field, *Buffer*, was added to the *Crash data by incident* table to account for crashes located within the DE site buffer based on latitude and longitude, milepoint, or intersecting road. If crashes landed in the DE site buffer area, they were assigned the appropriate DE site ID and DE project ID and added to the table.

Table 10: GDOT GEARS Search Terms used for DE Project 751300-

DE ID	Project ID	Roadway Search Term	Total Collisions
751300-3	751300-	Abernathy Rd	33
751300-3	751300-	Abernathy Rd Northeast	7
751300-3	751300-	Abernathy Road	5
751300-3	751300-	Abernathy Road Northeast	5
751300-3	751300-	GA 9	21
751300-3	751300-	GA9	890
751300-2	751300-	Johnson Ferry Rd	11
751300-2	751300-	Johnson Ferry Road	5
751300-1 and 751300-2	751300-	Riverside Dr	26
751300-1 and 751300-2	751300-	Riverside Drive	7
751300-3	751300-	Roswell Rd	107
751300-3	751300-	Roswell Road	34
751300-3	751300-	SR 9	5472
751300-3	751300-	SR9	2
751300-3	751300-	St Route 9	4
751300-3	751300-	St Rt 9	314
751300-3	751300-	St Rt9	1
751300-3	751300-	State Route 9	18
751300-3	751300-	State Rt 9	107
		Total	7069

Table 11: GDOT GEARS Search Terms used for DE Project 0004405

DE ID	Project ID	Roadway Search Term	Total Collisions
0004405_1, 0004405_2, and 0004405_3	0004405	Austell Rd	4
0004405_1	0004405	Floyd Rd	7
0004405_1	0004405	Floyd Road	1
0004405_1, 0004405_2, and 0004405_3	0004405	GA 5	7
0004405_1, 0004405_2, and 0004405_3	0004405	GA5	88
0004405_2	0004405	Sandtown Rd	5
0004405_2	0004405	Sandtown Road	2
0004405_1, 0004405_2, and 0004405_3	0004405	SR 5	4006
0004405_1, 0004405_2, and 0004405_3	0004405	SR5	32
0004405_1, 0004405_2, and 0004405_3	0004405	SR-5	1
		Total	4153

Table 12: Fields Included in Crash Table

Data Type	**Attribute**	**Data Source**
Crash Data by Incident	Accident Number	Veh Analysis 4 in GEARS
	Date	
	Time	
	County	
	Fatalities	
	Manner of Collision	
	Location of Impact	
	First Harmful Event	
	Light	
	Surface	
	Latitude	
	Longitude	
	Contributing Factors	
Crash Data by Person	Injury type (not injured, killed, serious, visible, complaint, blank)	Veh Analysis 6 in GEARS
Design Exception	DE Unique ID	Generated for each DE site
	DE Project ID	DE Request Form

DE sites 751300-1, 751300-2, and 751300-3 were analyzed at the same time during the development of the crash layer, as the three DE sites were impacted by many of the same roadways. A total of 7069 crashes were compiled for all of the roadways impacted by DE project 751300-. Of these, 5959 crashes included latitude and longitude information and mapped to particular locations in ArcGIS®, and crashes that fell within the DE analysis boundary were labeled with the appropriate DE site ID and DE project ID. This analysis identified 100 crashes that fell within the buffers of 751300-1, 751300-2, or 751300-3. For the 1110 crashes without latitude and longitude information, a second analysis based on milepoint information was conducted. Crashes were labeled with DE site and DE project IDs if they were located within the milepoint and RC Link associated with a polygon in the DE Layer.

Next, any crash that did not have latitude, longitude, or milepoint information was analyzed. Any crash with an intersecting street that matched the DE site was labeled with the correct information. The only crash associated with DE site 751300-1 and 751300-2 was identified by intersecting road, while DE 751300-3 had 125 crashes, which were identified with latitude and longitude, milepoint, and intersecting road. The flowchart in Figure 19 shows the process, and the map in Figure 21 shows the crashes identified by latitude and longitude for DE 751300-3.

This process was repeated for DE sites under the DE project 0004405 as illustrated by the flowchart in Figure 20. However, the DE sites 0004405_1, 0004405_2, and 0004405_3 only had crashes by accident based on latitude and longitude and had no crashes for milepoint or intersecting road. These crashes identified by latitude and longitude for DE 0004405_1 are shown in Figure 22.

After further analysis of crashes at DE sites 751300-1, 751300-2, 0004405_2, and 0004405_3, the researchers determined that analysis of these sites would not continue to the next step in the case study. DE sites 751300-1 and 751300-2 had no crashes during the study period with latitude and longitude. Though DE sites 0004405_2 and 0004405_3 had crashes during the DE construction time period, these sites did not have any crashes during the study period, three to five years before the DE approved date and one to three years after the DE build completion. For this reason, DE sites 0004405_2 and 0004405_3 were not analyzed further.

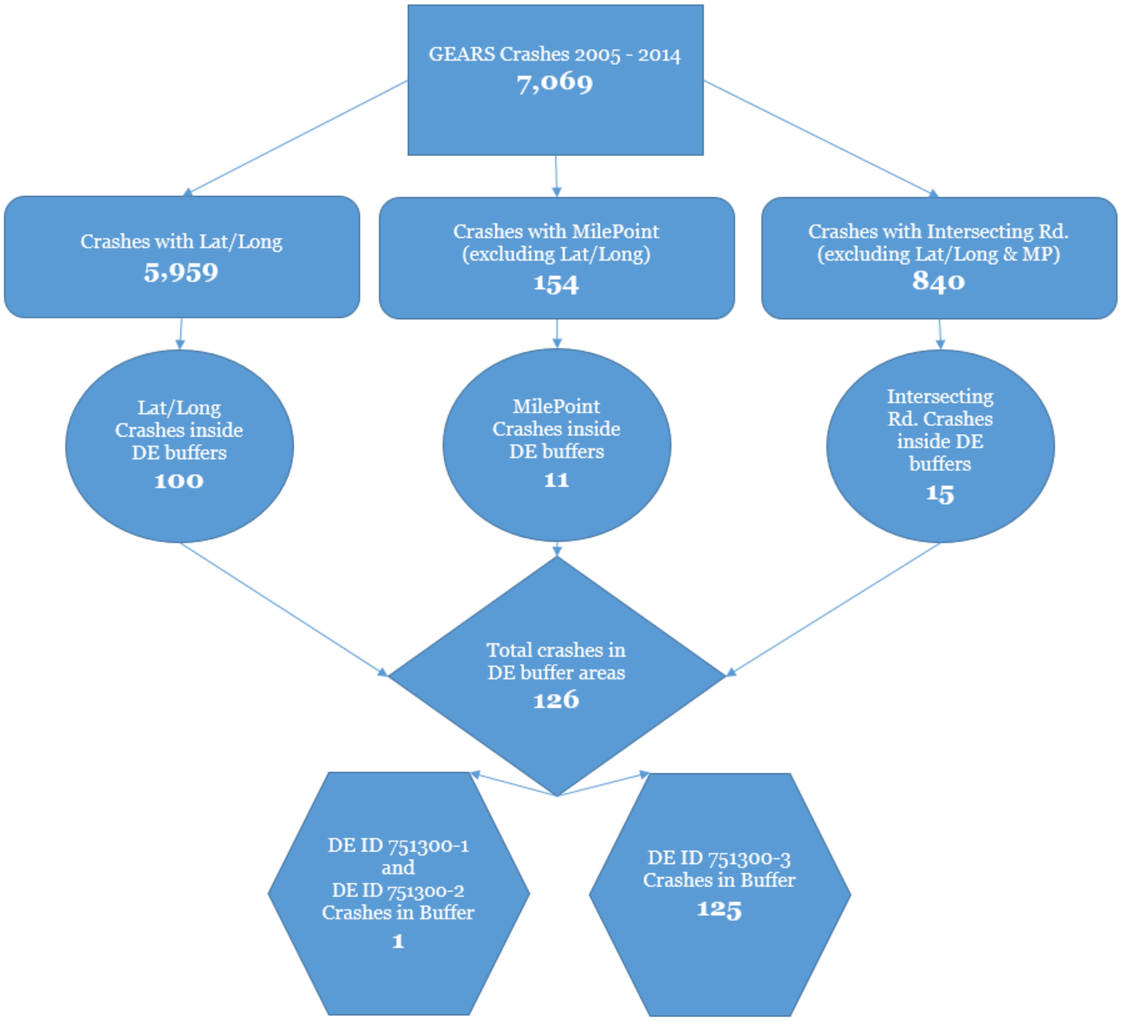


Figure 19: GEARS Crash Data 2005-2014 for DE 751300-1, DE 751300-2, and DE 751300-3

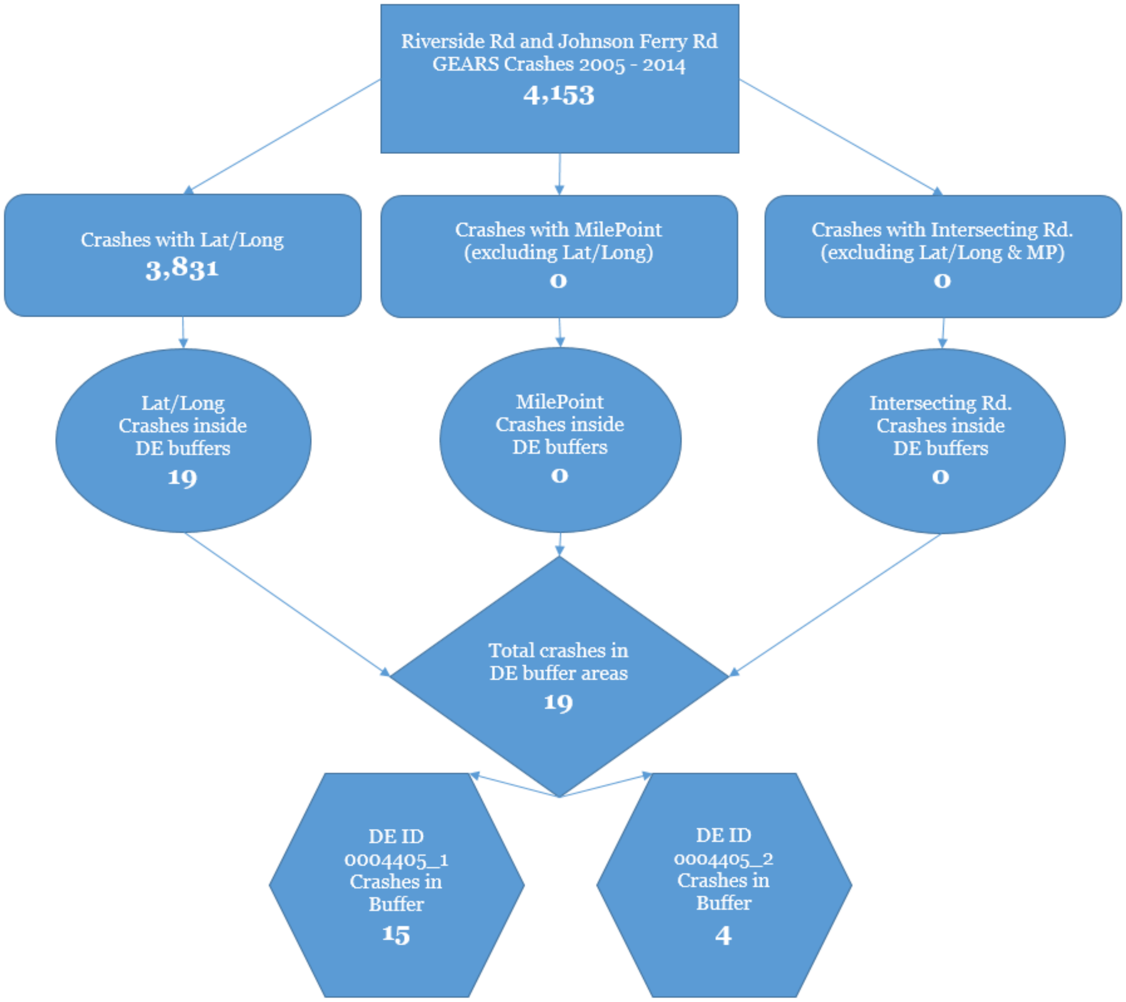


Figure 20: GEARS Crash Data 2005-2014 for DE 0004405_1, DE 0004405_2, and 0004405_3

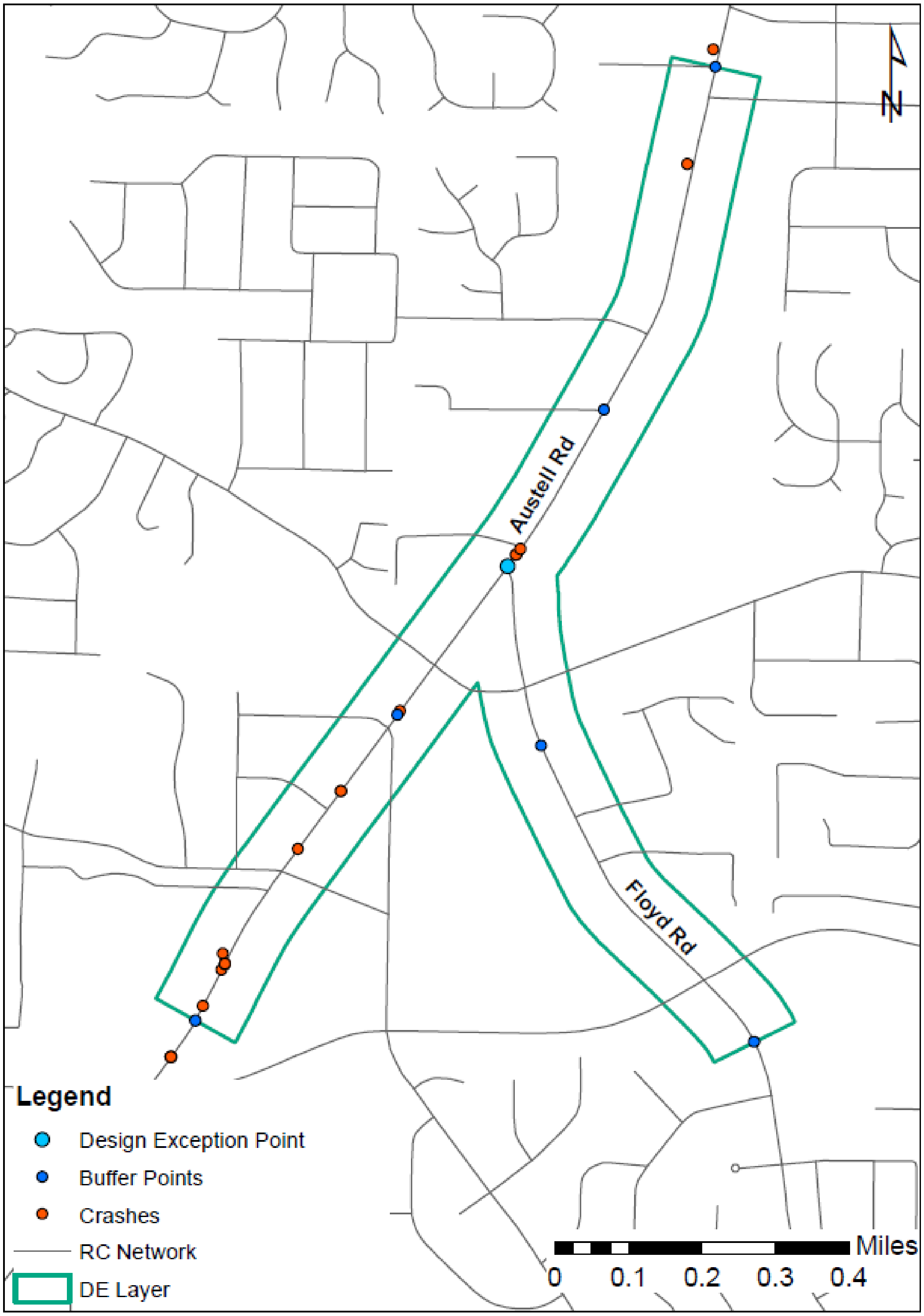


Figure 21: DE 0004405_1 Crashes with Latitude and Longitude

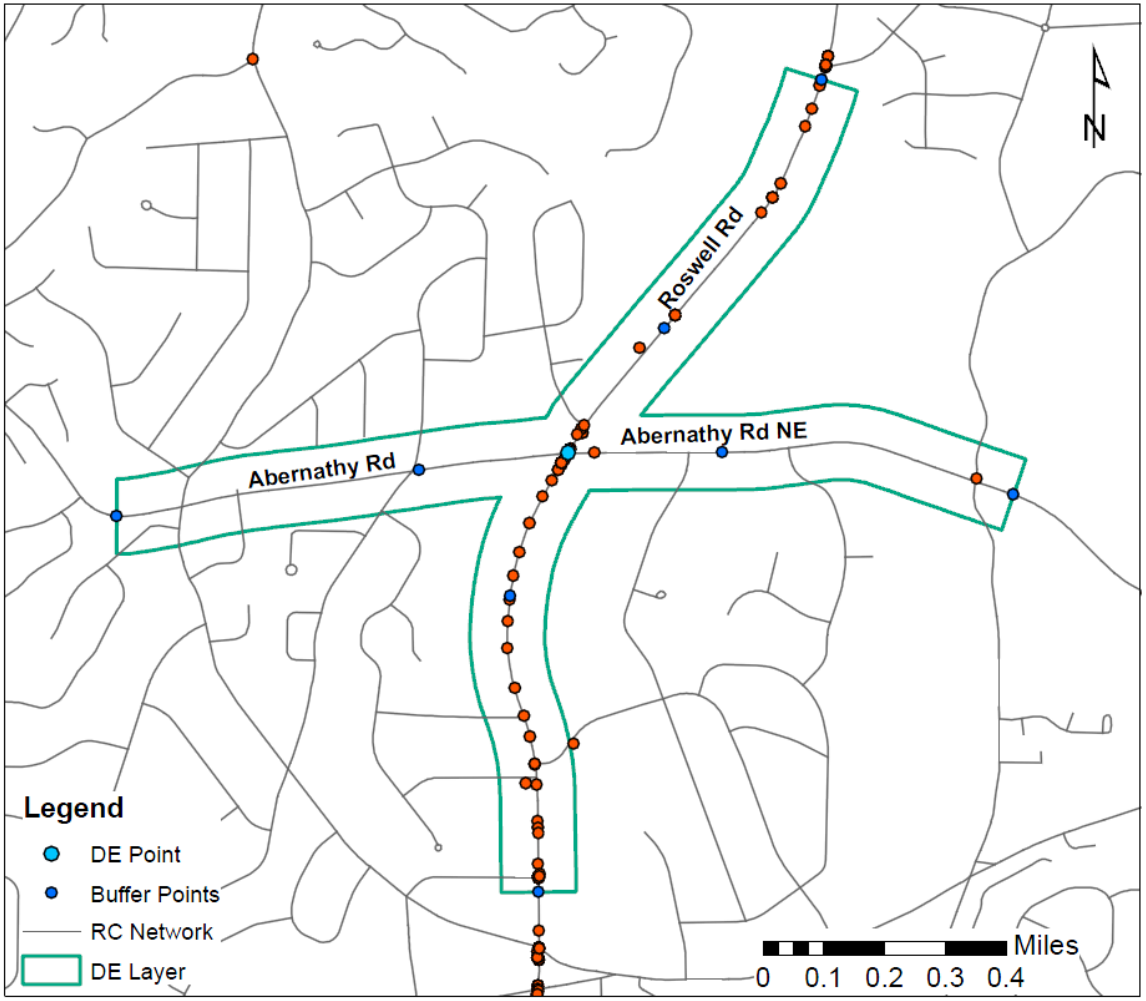


Figure 22: DE 751300-3 Crashes with Latitude and Longitude

Traffic Data Layer

The traffic data layer consists of information regarding roadway characteristics and traffic volumes. Table 13 summarizes the data and the data sources used in this layer. The researchers obtained annual average daily traffic data for the case study sites from the GDOT Traffic Counts website, *Geocounts*, and entered it manually into this layer. This process would be too time consuming for analysis of the entire DE database in implementation; however, a script could be used that would extract AADT for the years of analysis using count station ID.

The traffic count locations for DE sites 751300-3 and 0004500_1 are shown in Figure 23 and Figure 24, respectively. AADT were gathered for the years 2003 to 2014, as these years encompass the study period, three to five years before the DE approved date and one to three years after the DE build completion. Table 14 and Table 15 list the count station IDs and AADT for DE sites 751300-3 and 0004500_1. It should be noted that some of the count station sites had AADT missing for 2009. AADT was added to the RC Link layer attribute table by creating a new field for the years 2003–2014 and manually populating the traffic count data.

Table 13: Fields Included in Traffic Data Table

Data Type	Attribute	Data Source
Roadway Characteristics	Number of Through Lanes	RC Link layer
	Urban or Rural	
	Section Length	
Traffic Data	AADT	GDOT Traffic Counts: Geocounts

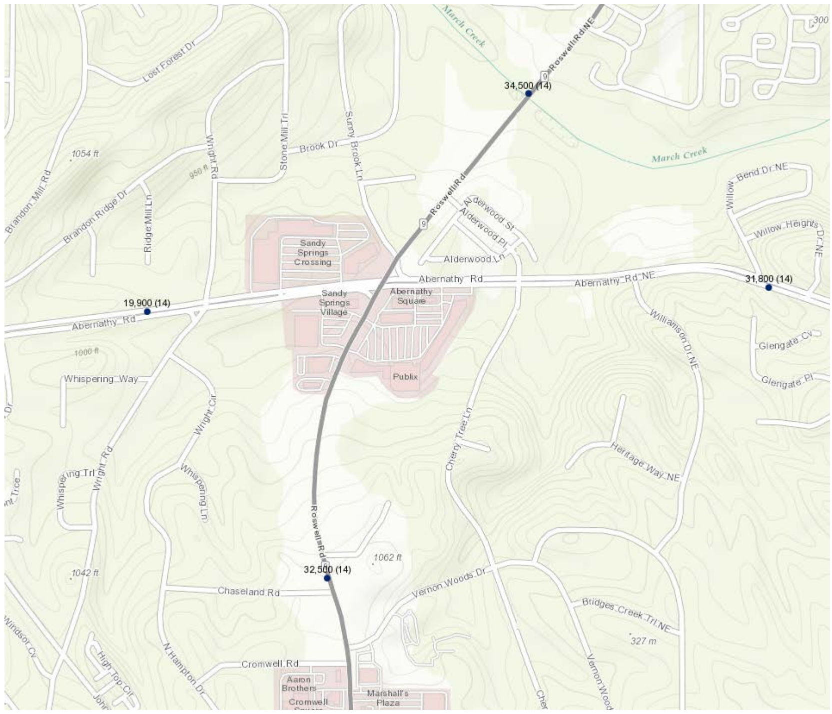


Figure 23: Portable Traffic Counter Locations for Roadways in DE 751300-3 Buffer Area

Table 14: AADT of Count Stations in DE 751300-3 Buffer Area

	Roswell Rd./SR 9 North of Intersection Station ID 1215122	Roswell Rd./SR 9 South of Intersection Station ID 1215120	Abernathy Rd West of Intersection Station ID 1216062	Abernathy Rd East of Intersection Station ID 1215668
2003	42,600	33,930	29,490	31,970
2004	27,910	34,200	30,020	32,540
2005	28,190	34,540	30,920	32,860
2006	36,940	32,180	21,570	31,910
2007	36,190	30,830	21,790	28,360
2008	34,060	31,250	16,550	26,690
2009	null	30,380	16,220	null
2010	31,570	32,500	19,320	30,120
2011	35,770	32,810	19,500	31,150
2012	36,380	28,720	19,830	31,680
2013	34,520	28,810	19,890	31,780
2014	34,500	32,500	19,900	31,800

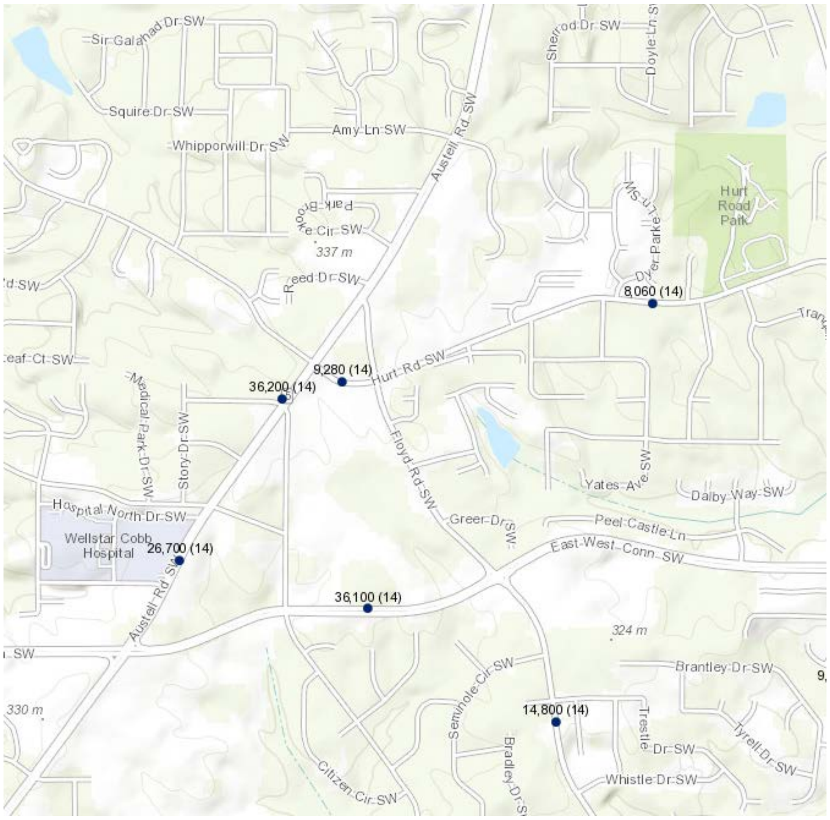


Figure 24: Portable Traffic Counter Locations for Roadways in DE 0004405_1 Buffer Area

Table 15: AADT of Count Stations in DE 0004405_1 Buffer Area

	Austell Rd NW of Intersection No Station ID	Austell Rd SW of Intersection Station ID 0672654	Floyd Rd SE of Intersection Station ID 0672339
2003	No counter	35,810	14,480
2004	No counter	36,450	15,920
2005	No counter	33,630	16,400
2006	No counter	36,700	16,910
2007	No counter	20,670	25,040
2008	No counter	19,460	24,900
2009	No counter	null	null
2010	No counter	38,180	16,960
2011	No counter	38,140	16,710
2012	No counter	29,750	16,680
2013	No counter	29,890	14,750
2014	No counter	36,200	14,800

Step Three: Case Study Initiate Design Exception Review

The DE sites were reviewed to determine if there were any crashes during the study period. DE sites 751300-1 and 751300-2 did not progress to further review as neither site had crashes with latitude and longitude information for the study period. DE sites 0004405_2 and 0004405_3 also did not progress since the roadways impacted by the overlapping DE buffers, Olive Springs Road and Sandtown Road, didn't have any crashes after DE construction ended. DE sites 751300-3 and 0004405_1 had crashes with latitude and longitude information in the crash database during the study period, so they progressed to *Initial Screen* in the evaluation process.

Evaluation Process

Step Four: Case Study Initial Screen, Total Crashes vs. Expected Crashes

The first step for analysts during the *Initial Screen* stage is to analyze the crash table for any fatalities or serious injuries. If there are any fatalities or serious injuries, then the DE site is moved to the *Candidate Design Exception Screen* step for further screening. If there are no fatalities or serious injury crashes, then the crashes at the DE site are analyzed under the *Initial Screen* step to determine if they meet either of the following criteria: (1) total crashes for current year of analysis exceed the expected number of crashes based on the appropriate *safety performance function*, or (2) including the current year, the proportion of non-severe injury crashes increased after the project was completed. If a DE site meets either of the screening criteria, then the DE site is progressed to the *Candidate Design Exception Screen*; if it does not, analysis of the site is completed at this step.

The DE 751300-3 site buffer includes Roswell Road/SR 9 and Abernathy Road. The first step completed by the analysts was to determine which roadway category or categories were located within the DE buffer to determine the appropriate SPF to use for establishing the expected number of crashes based on local conditions. The information necessary to determine SPF categorization is: route type, rural or urban/suburban, divided or undivided, and total through lanes. Two SPF categories also require information on roadway configuration: center two-way left-turn lane, urban or suburban three-lane arterials including a center two-way left-turn lane, or urban or suburban five-lane arterials including a center two-way left turn lane. The criteria for Roswell Road/SR 9 and Abernathy Road are summarized in Table 16. This information was gathered from the RC Link layer attribute table.

The Urban Code for both roadways was 03817 (Atlanta, GA). Both roadways were also classified as principal arterials with four total through lanes. However, Roswell Road at the DE site was undivided and Abernathy Road at the DE site was divided.

Table 16: Criteria Required to Determine SPF Formula for DE 751300-3

	Roswell Rd./SR 9	**Abernathy Rd.**	**Field Name in RC Link Layer**
Functional Class	Principal Arterial	Principal Arterial	F_SYSTEM
Rural or Urban/Suburban	Urban	Urban	URBAN_CODE
Divided or Undivided	Undivided	Divided	DIVIDED
Number of Through Lanes	4	4	TOTAL_LANE

The researchers determined that the SPF for Roswell Road/SR 9 should be calculated using the urban or suburban four-lane undivided arterial category, while the SPF for Abernathy Road should be calculated using the urban or suburban four-lane divided arterial category. See Table 17 for the SPF formulas that were used in the case study of DE 751300-3.

Table 17: SPF Formulas Used for DE 751300-3 Roadways

Roadway	Category	SPF	
Roswell Road/ SR 9	Urban or suburban four-lane undivided arterials	$N = exp^{(-11.63+1.33\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-7.99+0.81\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Abernathy Road	Urban or suburban four-lane divided arterials	$N = exp^{(-12.34+1.36\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-5.05+0.47\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)

DE 0004405_1 was also analyzed to determine the SPF category for the roadways in the buffer area: Austell Road and Floyd Road. Table 18 lists the criteria for the roadways and the fields in the RC Link attribute table for this site. Both Austell Road and Floyd Road were classified as urban minor arterial roadways. However, Austell Road was divided with four through lanes at the DE buffer site and Floyd Road was undivided with two through lanes at the DE buffer site.

A small section of Floyd Road from the East–West Connector to the far entrance of The Home Depot was labeled as four through lanes in the RC Link layer, while the rest of Floyd Road in the DE buffer was labeled as two through lanes. The researchers checked the through lane labeling with aerial imagery from Google Earth® and confirmed that all of Floyd Road in the DE buffer area should be labeled as two through lanes. The section of Floyd Road fronting The Home Depot is a complicated section of roadway with a large number of turn lanes and two through lanes that accommodate the commercial traffic of the area. The SPF for Austell Road was calculated using the urban or suburban four-lane undivided arterial category, while the SPF for Floyd Road was calculated by the researchers using the urban or suburban two-lane undivided arterial category. See

Table 19 for the SPF formulas that were used for the analysis of the DE 0004405_1 site.

Table 18: Criteria Required to Determine SPF Formula for 0004405_1

	Austell Road	**Floyd Road**	**Field Name in RC Link Layer**
Functional Class	Minor Arterial	Minor Arterial	F_SYSTEM
Rural or Urban/Suburban	Urban	Urban	URBAN_CODE
Divided or Undivided	Divided	Undivided	DIVIDED
Number of Through Lanes	4	2	TOTAL_LANE

Table 19: SPF Formulas Used for DE 0004405_1 Roadways

Road	**Category**	**SPF**	
Austell Road	Urban or suburban four-lane undivided arterials	$N = exp^{(-11.63 + 1.33 \times \ln(AADT) + \ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-7.99 + 0.81 \times \ln(AADT) + \ln(L))}$ (single-vehicle crashes)
Floyd Road	Urban or suburban two-lane undivided arterials	$N = exp^{(-15.22 + 1.68 \times \ln(AADT) + \ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-5.47 + 0.56 \times \ln(AADT) + \ln(L))}$ (single-vehicle crashes)

Table 20 and Table 21 show the AADT, segment length, and multi-vehicle or single-vehicle SPF for DE 751300-3, and Table 22 and Table 23 contain the AADT, segment length, and multi-vehicle or single-vehicle SPF for DE 0004405_1. The SPF for both DE sites was calculated in Microsoft Excel® using the current-year AADT and the segment length in the appropriate formula. DE 751300-3 is located at a four-way intersection, so four roadways are included in the DE buffer. Station count information was collected for all four roadway segments in the DE buffer for DE 751300-3. DE 0004405-3 is located at the center of a three-way intersection. Normally three roadway segments would be included in the SPF analysis; however, station count information was only gathered for one section of Austell Road and one section of Floyd Road, resulting in only two roadway segments for the calculation of the SPF.

Next, the predicted crash frequency was compared to the current-year crash frequency for the years of study after DE 751300-3 was completed, which included 2013 and 2014. The years with higher current-year crash frequency than predicted crash frequency are noted in red in Table 24 and Table 25. The crashes in Table 25 for DE 751300-3 were all assigned latitude and longitude information in the GDOT crash database. When all years 2005–2014 were considered, 24 crashes were also identified as being in the DE buffer based on intersecting road or milepoint information; however, it is unknown which sections of the DE buffer these crashes should be attributed to (Roswell Road north of intersection, Roswell Road south of intersection, Abernathy Road west of intersection, or Abernathy Road east of intersection). Ten crashes occurred in 2010, three in 2012, and eleven in 2013. One single-vehicle crash was identified as being located in the DE 751300-3 buffer based on intersecting road information; however, it is unknown which section of the DE buffer the crash should be assigned to. The single-vehicle crash occurred in 2009. The crashes without latitude and longitude information were excluded from the analysis. Only crashes with latitude and longitude information were identified for DE 0004405_1 with no crashes located using intersecting road or milepoint information. The SPF versus current-year analysis for DE 0004405_1 can be seen in Table 26 and Table 27.

Table 20: Multi-Vehicle Collision SPF for DE 751300-3

		Multi-Vehicle Collisions			
		exp^((-11.63+1.33×ln(AADT)+ln(L))		exp^((-12.34+1.36×ln(AADT)+ln(L))	
		Roswell Rd. North of Intersection	Roswell Rd. South of Intersection	Abernathy Rd. West of Intersection	Abernathy Rd. East of Intersection
	Year	Station ID 1215122	Station ID 1215120	Station ID 1216062	Station ID 1215668
AADT	2005	28,190	34,540	30,920	32,860
	2006	36,940	32,180	21,570	31,910
	2007	36,190	30,830	21,790	28,360
	2008	34,060	31,250	16,550	26,690
	2009	null	30,380	16,220	null
	2010	31,570	32,500	19,320	30,120
	2011	35,770	32,810	19,500	31,150
	2012	36,380	28,720	19,830	31,680
	2013	34,520	28,810	19,890	31,780
	2014	34,500	32,500	19,900	31,800
Segment Length (miles)		0.75	0.75	0.75	0.75
SPF	2005	5.53	7.25	4.19	4.56
	2006	7.92	6.60	2.57	4.38
	2007	7.71	6.23	2.61	3.73
	2008	7.11	6.34	1.79	3.43
	2009	null	6.11	1.74	null
	2010	6.43	6.68	2.21	4.05
	2011	7.59	6.77	2.24	4.24
	2012	7.77	5.67	2.29	4.33
	2013	7.24	5.69	2.30	4.35
	2014	7.24	6.68	2.30	4.36

Table 21: Single-Vehicle Collision SPF for DE 751300-3

		Single-Vehicle Collisions			
		exp^((-7.99+0.81×ln(AADT)+ln(L))		exp^((-5.05+0.47×ln(AADT)+ln(L))	
		Roswell Rd. North of Intersection	**Roswell Rd. South of Intersection**	**Abernathy Rd. West of Intersection**	**Abernathy Rd. East of Intersection**
	Year	**Station ID 1215122**	**Station ID 1215120**	**Station ID 1216062**	**Station ID 1215668**
AADT	2005	28,190	34,540	30,920	32,860
	2006	36,940	32,180	21,570	31,910
	2007	36,190	30,830	21,790	28,360
	2008	34,060	31,250	16,550	26,690
	2009	null	30,380	16,220	null
	2010	31,570	32,500	19,320	30,120
	2011	35,770	32,810	19,500	31,150
	2012	36,380	28,720	19,830	31,680
	2013	34,520	28,810	19,890	31,780
	2014	34,500	32,500	19,900	31,800
Segment Length (miles)		0.75	0.75	0.75	0.75
SPF	2005	1.02	1.21	0.62	0.64
	2006	1.27	1.14	0.52	0.63
	2007	1.25	1.10	0.53	0.60
	2008	1.19	1.11	0.46	0.58
	2009	null	1.09	0.46	null
	2010	1.12	1.15	0.50	0.61
	2011	1.24	1.16	0.50	0.62
	2012	1.26	1.04	0.50	0.63
	2013	1.20	1.04	0.50	0.63
	2014	1.20	1.15	0.50	0.63

Table 22: Multi-Vehicle Collision SPF for DE 0004405_1

		Multi-Vehicle Collisions	
		exp^((-11.63+1.33×ln(AADT)+ln(L))	exp^((-15.22+1.68×ln(AADT)+ln(L))
		Austell Rd	**Floyd Rd**
	Year	**Station ID 0672654**	**Station ID 0672339**
AADT	2005	33,630	16,400
	2006	36,700	16,910
	2007	20,670	25,040
	2008	19,460	24,900
	2009	n/a	n/a
	2010	38,180	16,960
	2011	38,140	16,710
	2012	29,750	16,680
	2013	29,890	14,750
	2014	36,200	14,800
Segment Length (miles)		1.5	0.75
SPF	2005	13.99	2.22
	2006	15.71	2.34
	2007	7.32	4.52
	2008	6.76	4.47
	2009	null	null
	2010	16.56	2.35
	2011	16.54	2.29
	2012	11.88	2.28
	2013	11.96	1.86
	2014	15.43	1.87

Table 23: Single-Vehicle Collision SPF for DE 0004405_1

		Single-Vehicle Collisions	
		exp^((-7.99+0.81×ln(AADT)+ln(L))	exp^((-5.47+0.56×ln(AADT)+ln(L))
		Austell Rd	**Floyd Rd**
	Year	**Station ID 0672654**	**Station ID 0672339**
AADT	2005	33,630	16,400
	2006	36,700	16,910
	2007	20,670	25,040
	2008	19,460	24,900
	2009	n/a	n/a
	2010	38,180	16,960
	2011	38,140	16,710
	2012	29,750	16,680
	2013	29,890	14,750
	2014	36,200	14,800
Segment Length (miles)		1.5	0.75
SPF	2005	2.36	0.72
	2006	2.53	0.74
	2007	1.59	0.92
	2008	1.51	0.91
	2009	null	null
	2010	2.61	0.74
	2011	2.61	0.73
	2012	2.14	0.73
	2013	2.14	0.68
	2014	2.50	0.68

Table 24: DE 751300-3 Multi-Vehicle Crashes (SPF vs Current-Year Crashes)

		Multi-Vehicle Collisions			
		Roswell Rd. North of Intersection	Roswell Rd. South of Intersection	Abernathy Rd West of Intersection	Abernathy Rd East of Intersection
	Year	Station ID 1215122	Station ID 1215120	Station ID 1216062	Station ID 1215668
SPF	2013	7.24	**5.69**	2.30	4.35
	2014	**7.24**	6.68	2.30	4.36
Current-year crashes	2013	7	**9**	0	0
	2014	**9**	6	0	0

Table 25: DE 751300-3 Single-Vehicle Crashes (SPF vs Current-Year Crashes)

		Single-Vehicle Collisions			
		Roswell Rd. North of Intersection	Roswell Rd. South of Intersection	Abernathy Rd West of Intersection	Abernathy Rd East of Intersection
	Year	Station ID 1215122	Station ID 1215120	Station ID 1216062	Station ID 1215668
SPF	2013	1.20	1.04	0.50	0.63
	2014	1.20	1.15	0.50	0.63
Current-year crashes	2013	0	1	0	0
	2014	0	0	0	0

Table 26: DE 0004405_1 Multi-Vehicle Crashes (SPF vs Current-Year Crashes)

		Multiple-Vehicle Collisions	
		Austell Rd	Floyd Rd
	Year	Station ID 0672654	Station ID 0672339
SPF	2011	16.54	2.29
	2012	11.88	2.28
	2013	11.96	1.86
	2014	15.43	1.87
Current-year crashes	2011	0	0
	2012	0	0
	2013	0	0
	2014	0	0

Table 27: DE 0004405_1 Single-Vehicle Crashes (SPF vs Current-Year Crashes)

		Single-Vehicle Collisions	
		Austell Rd	Floyd Rd
	Year	Station ID 0672654	Station ID 0672339
SPF	2011	2.61	0.73
	2012	2.14	0.73
	2013	2.14	0.68
	2014	2.50	0.68
Current-year crashes	2011	0	0
	2012	0	0
	2013	0	0
	2014	0	0

The analysis identified several years for the DE site 751300-3 where current-year crash frequency exceeded predicted crash frequency for multi-vehicle crashes. However, no instances of current-year crash frequency exceeding SPF were found for DE 751300-3 single-vehicle crashes. The multiple-vehicle crash analysis seen in Table 26 and the single-vehicle crash analysis seen in Table 27 did not reveal any current-year crashes that occurred at a higher frequency than predicted crashes.

Under a full DE monitoring program, since the current-year crashes of DE 751300-3 exceeded the threshold, the DE site would be moved directly to the *Candidate Design Exception Screen* and would not require analysis under the last screen of the *Initial Screen*, a hypothesis test determining if there was an increase in crash severity when comparing before and after build. However, for the purposes of the case study, DE 751300-3 was analyzed using the *Initial Screen* hypothesis test. DE 0004405_1 would also be analyzed further under a full DE monitoring program since the DE was not found to have higher current-year crash frequency that predicted crash frequency. However, DE 0004405_1 had zero multi-vehicle or single-vehicle crashes at the DE site for the years after the project was completed, 2013 and 2014, so DE 0004405_1 was not analyzed further in the case study.

Initial Screen: Hypothesis Test of Crash Severity

The final screening criterion under the *Initial Screen* is a hypothesis test to determine if there was an increase in crash severity for the total crashes by comparing property damage only crashes to injury crashes for all crashes at the DE site. This analysis was completed in Microsoft Excel® and the results for DE 751300-3 are shown in

Table 28. A hypothesis test on crash severity was conducted using the formula below and by assuming p_1 is the proportion of injuries and fatalities before the project, and p_2 is the proportion of injuries and fatalities after the project. The hypothesis test is $H_0: p_2 \leq p_1$ versus $H_a: p_2 > p_1$.

The Z test statistic is used as shown below:

$$Z = \frac{\widehat{p_1} - \widehat{p_2}}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})}}$$

where $\hat{p}$ is the combined before and after proportion of injuries and fatalities, and n_1 and n_2 are the number of crashes before and after the project, respectively. As such, an α-level test rejects the null hypothesis when $|Z| > z_\alpha$, where z_α denotes the $(1-\alpha)100th$ percentile of a standard normal distribution, and z_α = 1.645

Further explanation of the hypothesis test can be found in the Theoretical Foundation supplemental section of the report in Appendix B. The analysis of DE 751300-3 for the case study can be seen in

Table 28. As absolute Z was not greater than z_α, the researchers failed to reject the null hypothesis and thus cannot say that the proportion of injuries after the DE was built was greater than the proportion of crashes before the DE was built. However, since the number of actual crashes exceeded the predicted crashes at DE 751300-3 during the study period, the DE site was moved to the *Candidate Design Exception Screen*.

Table 28: Initial Screen Hypothesis Test: Crash Severity

	Year	PDO	Injury	Total
Pre-Build	2005	0	0	0
	2006	9	2	11
	2007	7	3	10
Total		16	5	21
Proportion		0.76190476	0.23809524	
Post-Build	2013	16	1	17
	2014	14	1	15
Total		30	2	32
Proportion (2013)		0.941176471	0.058823529	
Proportion (2014)		0.933333333	0.066666667	
Proportion (2013 + 2014)		0.9375	0.0625	

Pre-build vs. 2013	Hypothesis test: Crash Severity (PDO vs. Injury)	0.456534399	p	0.157894737
Pre-build vs. 2014		0.425051932	p	0.166666667
Pre-build vs. 2013 + 2014		0.489003208	p	0.132075472

Step Five: Case Study Candidate Design Exception Screen

The first step of the *Candidate Design Exception Screen* is to analyze the crash table for any fatalities or serious injuries for the years of analysis. If there are any fatalities or serious injuries, then the DE site moves directly to *Full Review*. The *Candidate Design Exception Screen* analyzes DE sites to determine (1) if there is an increase in the frequency of total crashes that could be associated with DE type, and (2) if there in an increase in the proportion of non-severe injury crashes that could be associated with the DE type. If a DE site meets either of these screening criteria, then the DE site is moved to the *Full Review* screening step.

After ruling out any fatalities or serious injuries at the DE site, the next step for analysts is to categorize crashes at the DE site as potentially associated with the DE type or not potentially associated with the DE type. To aid in this analysis, researchers created a resource table to identify terms under the attribute field in the *Crash data by incident* table that correspond to crash types potentially associated with specific DE types based on the earlier literature review.
DE 751300-3 is classified as a horizontal alignment DE type, and Table 29 lists the crash types that potentially are associated with the horizontal alignment DE type. The full table, which lists the crash types that are potentially associated with all 13 DE types, is located in Appendix E. As seen in Table 29, some crash types were identified in the literature as applicable to certain DE types for specific facilities. However, some sources did not include facility-specific information.

Table 29: Crash Type in Literature with Terminology and Field in GEARS Crash Table

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Horizontal Alignment	Run-off-road	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Cross-median	Head-on	Manner of Collision
	Cross-centerline	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
	Large vehicle rollover	Overturn	First Harmful Event
	Skidding	Weather conditions	Contributing Factors
		Driver lost control	Contributing Factors
		Too fast for conditions	Contributing Factors
	Rear-end crashes if operations deteriorate (abrupt speed reduction)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Train-vehicle collision at sharp crossing angle	Railway train	First Harmful Event
	Unknown	Other	Contributing Factors
		Blank cell	Contributing Factors

The primary source of vehicle crash information in the state of Georgia is the Georgia Uniform Motor Vehicle Accident Report Form. Information from this form provides the basis for the Georgia Accident Reporting System (Georgia Department of Transportation, 2003). Appendix G provides an example of the Georgia Uniform Motor Vehicle Accident Report Form. Information from the Georgia Uniform Motor Vehicle Accident Report Form is summarized in the GDOT GEARS system in crash tables with information by accident, by vehicle, etc. For example, the *Crash data by incident* table, referred to as Veh Analysis 4 in GEARS, was used in the *Candidate Design Exception Screen*. This *Crash data by incident* table includes several attribute fields that are important for identifying crashes that may be associated with a particular DE type, including:

1. Manner of Collision
2. First Harmful Event
3. Contributing Cause Veh 1
4. Contributing Cause Veh 2

Table 30 shows the crash table for 2013 and Table 31 shows the crash table for 2014 for the horizontal alignment DE site, 751300-3. Table 32 summarizes the crashes that were identified as potentially caused by the horizontal alignment DE type for the three years before the DE site was built and the current years of study, 2013 and 2014. Only the crashes identified as potentially caused by the DE type were analyzed during the *Candidate Design Exception Screen* hypothesis test, and are outlined below.

Table 30: DE 751300-3 Crashes in 2013

Meets Criteria	Manner of Collision	First Harmful Event	Contributing Cause Veh 1	Contributing Cause Veh 2
Y	Not A Collision with Motor Vehicle	Other - Fixed Object	No Contributing Factors	Blank
Y	Rear End	Motor Vehicle In Motion	Changed Lanes Improperly	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close, Mechanical Or Vehicle Failure	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Head On	Motor Vehicle In Motion	Driver Lost Control, Distracted	Blank
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Angle	Motor Vehicle In Motion	Blank	No Contributing Factors
Y	Sideswipe-Same Direction	Motor Vehicle In Motion	Blank	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
N	Sideswipe-Same Direction	Motor Vehicle In Motion	Changed Lanes Improperly	No Contributing Factors
Y	Angle	Motor Vehicle In Motion	Other	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close, Distracted	No Contributing Factors

Table 31: DE 751300-3 Crashes in 2014

Meets Criteria	Manner of Collision	First Harmful Event	Contributing Cause Veh 1	Contributing Cause Veh 2
N	Sideswipe-Same Direction	Motor Vehicle In Motion	Improper Turn	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close,Other	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Head On	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
Y	Sideswipe-Opposite Direction	Motor Vehicle In Motion	Blank	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
Y	Head On	Motor Vehicle In Motion	Other	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Following too Close	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors
N	Angle	Motor Vehicle In Motion	Failed to Yield	No Contributing Factors
Y	Rear End	Motor Vehicle In Motion	Following too Close	No Contributing Factors

Table 32: DE 751300-3 Crashes Potentially Associated with DE Type

	Year	Criteria Met	Criteria Not Met	Total
Pre-Build	2005	1	0	1
	2006	8	3	11
	2007	4	6	10
Post-Build	2013	11	6	17
	2014	8	7	15

Candidate Design Exception Screen: Hypothesis Test of Increase in Frequency of All Potentially DE-Associated Crashes

The first hypothesis test in the *Candidate Design Exception Screen* focuses on the potential increase in frequency of potential DE-associated crashes after a project is built. Appendix F includes computer code that will allow this analysis to be completed in the popular "R" statistical package (available at https://www.**rstudio**.com/). A discussion of the theoretical foundation of the method is provided elsewhere in the report. Results of the hypothesis test for the case study site (751300-3) are presented in Table 33. The hypothesis tests of all three scenarios—pre-build vs. 2013, pre-build vs. 2014, and pre-build vs. 2013 and 2014—failed to reject the null hypothesis at the 95% confidence level. As such, the research team cannot say that the frequency of potentially DE-associated crashes increased after the build.

Table 33: Hypothesis Test of Increase in Frequency of All Potentially DE-Associated Crashes

	Year	Crashes
Pre-Build	2005	1
	2006	8
	2007	4
Post-Build	2013	11
	2014	8

p value	**Pre-build vs. 2013**	0.1204607
	Pre-build vs. 2014	0.1288251
	Pre-build vs. 2013 + 2014	0.1036869

Candidate Design Exception Screen: Hypothesis Test of Increase in Severity of Potentially DE-Associated Crashes (PDO vs Injury)

The final screening criterion under the *Candidate Design Exception Screen* is the hypothesis test to determine if there was an increase in crash severity for the crashes potentially associated with the DE type by comparing PDO crashes to non-severe injury crashes. A hypothesis test of all PDO vs injury crashes was conducted earlier in the *Initial Screen* step. The analysis of only crashes potentially related to the DE type was completed in Microsoft Excel®, and the results for DE 751300-3 can be seen in Table 34. The hypothesis test on crash severity is described in further detail in the Theoretical Foundation section of the report (Appendix B).

Table 34: Hypothesis Test of Increase in Crash Severity of Crashes Potentially Associated with DE Type

	Year	PDO	Injury	Total
Pre-Build	2005	1	0	1
	2006	6	2	8
	2007	4	2	6
Total		11	4	15
Proportion		0.733333333	0.266666667	
Post-Build	2013	14	0	14
	2014	9	0	9
Total		23	0	23
Proportion (2013)		1	0	
Proportion (2014)		1	0	
Proportion (2013 + 2014)		1	0	

Pre-build vs. 2013	Hypothesis test: Crash Severity (PDO vs. Injury)	**0.728804967**	p	0.137931034
Pre-build vs. 2014		**0.663006743**	p	0.166666667
Pre-build vs. 2013 + 2014		**0.83426519**	p	0.105263158

Absolute Z was not greater than z_{α}, so the null hypothesis (that the results were not different before and after construction) was not rejected. Thus, the proportion of injuries after the DE site was built was not greater than the proportion of crashes before the DE site was built.

Since none of the current-year crashes exceeded the threshold, the DE site would not be moved on for *Full Review* in an actual DE monitoring program. In a full DE monitoring program, the analyst would update the date of the most recent review and review comments for DE 751300-3, and the DE site would be reviewed again the next year unless the DE site had been reviewed for three years. If the DE site had been reviewed for three consecutive years and had not exceeded the threshold any of those years, then the DE 751300-3 would be reclassified and a review would not be conducted the next year. For the sake of the case study, DE 751300-3 was analyzed further under the *Full Review* screen.

Step Six: Case Study Full Review

Under the *Full Review* screen, crashes at the DE site are analyzed using the following procedure: (1) sample the total crashes for the current year of analysis (all crashes if less than 20); (2) gather and analyze crash reports for the sampled crashes to determine if one or more crashes could be potentially associated with DE type; (3) determine if any effect(s) exceed a threshold limit; and (4) if the effect threshold is exceeded, then a *Road Safety Audit* is recommended; otherwise, the analysis is terminated and the database updated.

Crashes at DE 751300-3 from 2013–2014, two years after the DE site was built, were analyzed in the case study. There were 17 crashes in 2013 and 15 crashes in 2014, (i.e., less than 20 for each year) and thus all crash reports were gathered and analyzed. Appendix G lists the criteria from the Georgia Uniform Vehicle Accident Report that were used in this analysis. First Harmful Event applies to the accident as a whole, while Most Harmful Event applies to individual vehicles or pedestrians (Georgia Department of Transportation, 2003). After analyzing the crash reports, the researchers determined that none of the crashes during the study years were associated with the DE type and, thus, no *Road Safety Audit* was recommended.

Analysis of these crash reports did provide some important information in recognizing the limits of these analyses. In particular, the *Police Remarks* and *Crash Diagrams* allowed greater insight into crash details than could be inferred by analysis of the GEARS data alone. For example, the manner of collision for two crashes in 2014 were misclassified (i.e., one Rear End Collision misclassified as an Angle collision and another the reverse case). Three crashes in 2013 were found to have no *Police Remarks*.

Appendix B: Theoretical Foundations

Underlying Statistical Model

In this report, the researchers model crash frequency using the negative binomial (NB) distribution. The negative binomial distribution is the most widely adopted statistical distribution in safety research (Lord & Mannering, 2010). For example, the safety performance functions in the Highway Safety Manual are based on the negative binomial distribution. In a recent study on the safety impacts of DE types, Wood and Porter (2013) also assumed the negative binomial distribution in their modeling approach.

Following the discussions in Grandell (1997), Hougaard et al. (1997), and Lawless (1987), the number of crashes at a site for a given year are denoted as Y. The count random variable Y has a negative binomial distribution, denoted by $NB(\mu, \theta)$, with probability mass function (pmf)

$$P(Y = y) = \frac{\Gamma(y+\theta)}{\Gamma(\theta)\Gamma(y+1)} \frac{\theta^{\theta}\mu^{y}}{(\theta+\mu)^{(\theta+y)}}, y = 0, 1, \dots, \mu > 0, \theta > 0$$

where $\Gamma(\cdot)$ is the gamma function. The NB distribution has the following characteristics:

- The mean of Y is $E(Y) = \mu$
- The variance of Y is $V(Y) = \mu + \mu^2/\theta$

Hypothesis Testing about Crash Frequency

One of the screening steps in the DE monitoring program is to ascertain if there is indeed a change in crash frequency of crashes potentially associated with the DE type after a project is built. The yearly crash frequencies before the DE are denoted as $X_1, \dots, X_m$ with pmf $NB(\mu_X, \theta_X)$. Similarly, the yearly crash frequencies after the DE are denoted as $Y_1, \dots, Y_n$ with pmf $NB(\mu_Y, \theta_Y)$. Assume that $X_1, \dots, X_m$ and $Y_1, \dots, Y_n$ are independent. Let $\mu_X = \mu$, $\theta_X = \theta$, $\mu_Y = \gamma\mu$, and $\theta_Y = \theta$, where $\mu > 0$, $\theta > 0$, and $\gamma > 0$.

Under this framework, γ represents the effect of the project, whether or not this effect is attributable to the DE. If $\gamma = 1$, there is no safety impact from the project; otherwise, there is an impact from the project, and the site warrants further investigation. As such, the hypothesis test is formulated as $H_0: \gamma \leq 1$ versus $H_a: \gamma > 1$. Because the distribution of crash frequencies does not conform to the normal distribution, the *t*-test is not appropriate. Alternatively, one can utilize the Wilcoxon rank sum test (Lehmann, 1975), which is a non-parametric method. The drawback of using the Wilcoxon rank sum test is that it is less powerful than parametric methods. Following recommendations by Aban et al. (2009), a likelihood-based inference method known as the score test was adopted (Cox & Hinkley, 1974). Aban et al. (2009) derived the test statistic as,

$$Z_S = \frac{(\bar{y} - \hat{\mu}_0)}{(\hat{\theta}_0 + \hat{\mu}_0)} \sqrt{\frac{n\hat{\theta}_0[m(\hat{\theta}_0 + \hat{\mu}_0) + n(\hat{\theta}_0 + \hat{\mu}_0)]}{m\hat{\mu}_0}}$$

where $\hat{\mu}_0$ and $\hat{\theta}_0$ solve the system of equations,

$$\begin{cases} \hat{\mu}_0 = \frac{\sqrt{[m(\bar{x}-\hat{\theta}_0)+n(\bar{y}-\hat{\theta}_0)]^2+4\hat{\theta}_0(m+n)(m\bar{x}+n\bar{y})}}{2(m+n)} + \frac{m(\bar{x}-\hat{\theta}_0)+n(\bar{y}-\hat{\theta}_0)}{2(m+n)} \\ 0 = -(m+n)\left[\Psi(\hat{\theta}_0) - 1\right] + \sum_{i=1}^{m} \Psi(x_i + \hat{\theta}_0) + \sum_{j=1}^{n} \Psi(y_j + \hat{\theta}_0) + m\ln(\frac{\hat{\theta}_0}{\hat{\theta}_0+\hat{\mu}_0}) \end{cases},$$

and $\Psi(\cdot)$ denotes the digamma function.

Under the conditions defined above, an approximate α-level test for $H_0: \gamma \leq 1$ versus $H_a: \gamma > 1$ rejects H_0 when $z_S > z_\alpha$, where z_α denotes the $(1-\alpha)100th$ percentile of a standard normal distribution. For most safety research, α is taken to be in the range of 0.001 to 0.05. For this study the researchers assume α=0.01.

Hypothesis Testing about Crash Severity

A test to determine if the proportion of injuries and fatalities has increased should be run for total crashes in the *Initial Screen* step and only for crashes potentially associated with the DE type in the *Candidate Design Exception Screen* step. The analysis assumes p_1 is the proportion of injuries and fatalities before the project, and p_2 is the proportion of injuries and fatalities after the project. The analyst is interested in the hypothesis test $H_0: p_2 \leq p_1$ versus $H_a: p_2 > p_1$.

The Z test statistic shown below is used:

$$Z = \frac{\widehat{p_1} - \widehat{p_2}}{\sqrt{\hat{p}(1-\hat{p})(\frac{1}{n_1} + \frac{1}{n_2})}}$$

where $\hat{p}$ is the combined before and after proportion of injuries and fatalities, and n_1 and n_2 are the number of crashes before and after the project, respectively. As such, an α-level test rejects the null hypothesis when $|Z| > z_\alpha$, where z_α denotes the $(1-\alpha)100th$ percentile of a standard normal distribution.

Development of Crash Report Sampling Rate

Once a DE site progresses to the *Full Review* screen, the analyst should randomly sample current-year crash reports for the DE site if there are more than 20 crashes for the current year of study. If there are less than 20 crashes for the current year of study, then all crash reports should be reviewed. The number of crash reports to be sampled is selected based on the hypergeometric distribution, which describes the probability of k successes in n draws without replacement from a finite population. In this case, the population is all current-year crashes at the DE site. The population size is denoted as N. The researchers assume that the acceptable threshold for the effect of the DE type, denoted as p, is 20%. As such, the number of crashes associated with the DE type, denoted as K, equals $0.2N$. The probability of obtaining k crashes that are associated with the DE type from a sample size n is:

$$P(X = k) = \frac{\binom{K}{k}\binom{N-K}{n-k}}{\binom{N}{n}}$$

The goal is to be 95% confident that the sample crash reports obtain at least one crash that is potentially associated with the DE type. This objective can be written as:

$$P(X \geq 1) \equiv 1 - P(X = 0) \geq 0.95$$

This is equivalent to:

$$P(X = 0) \equiv \frac{\binom{K}{0}\binom{N-K}{n-0}}{\binom{N}{n}} \leq 0.05$$

where N and K are known. Thus, one can find the minimum n using a standard software, such as the HYGEOM.DIST function in Microsoft Excel®.

Appendix C1: Proposed Request for Design Exception Form

DEPARTMENT OF TRANSPORTATION

STATE OF GEORGIA

INTEROFFICE CORRESPONDENCE

REQUEST FOR DESIGN EXCEPTION (or VARIANCE)

FILE P.I. Number

Project Number (if available)

County

Project Description

OFFICE Design Office

DATE Date

FROM Office Head (GDOT Submitting Office, otherwise engineering firm letterhead)

TO State Design Policy Engineer

SUBJECT Request for Design Exception (or Variance) for (list criteria here) ex: Shoulder Width Approval of a Design Exception (or Variance) is requested for this project.

PROJECT DESCRIPTION Provide a general description of the project including the length of the project, the general location of the project including any city and county limits or proximity thereto, speed design, posted speed limit, and describe the proposed typical sections and other major improvements to be constructed.

DESIGN EXCEPTION/VARIANCE List design exception or design variance type proposed

FEATURE(S) REQUIRING A DESIGN EXCEPTION/VARIANCE Describe the feature(s) requiring a design exception or a design variance. Give the values of the current standard criteria and the values that are proposed to be used. Include the latitude and longitude of the beginning and ending point(s) of the design exception.

CURRENT AND FUTURE TRAFFIC DATA Describe current and future traffic volumes with any other pertinent traffic data.

CRASH DATA/ SUBSTANTIVE SAFETY RISK Describe the crash history within the project limits for the last three years. In particular, address and summarize the crash type history related to the design exception or variance type under request. Include the latitude and longitude of the beginning and ending point(s) of the roadway that may be impacted by the design exception.

WHY THE CURRENT STANDARD CRITERIA CANNOT BE MET Summarize why the current AASHTO Standard Controlling Criteria (Design Exception)/GDOT Standard Criteria (Design Variance) cannot be met.

COST TO MEET STANDARD CRITERIA Summarize the cost estimate for construction and right-of-way and other associated costs for constructing or reconstructing the design feature to meet current standards.

MITIGATION PROPOSED Describe any mitigation proposed to lessen the impact of not meeting current standard criteria. (FHWA publication Mitigation Strategies for Design Exceptions is a good reference) If mitigation or other additional enhancement costs are significant, summarize these costs at this point.

RECOMMENDATION The Engineer/Designer of Record must make a recommendation to the approving authority for action. Any conditions to the approval of this exception should be clearly stated. Include name and contact number.

The signature block for approval will take one or the other of the following forms:

For projects NOT classified as Full Oversight (FOS) or Project of Division Interest (PoDI):
Recommend: (Include this line for consultant designed projects only)________________

Engineer of Record Date

Concur:____

GDOT Director of Engineering Date

Approve:____

GDOT Chief Engineer Date

For projects classified as Full Oversight (FOS) or Project of Division Interest (PoDI):

Recommend: (Include this line for consultant designed projects only)________________

Engineer of Record Date

Concur:____

GDOT Director of Engineering Date

Approve:____

GDOT Chief Engineer Date

Approve:____

FHWA Division Administrator Date

Required attachments: plan/profile sheets

Other attachments: Location sketch, typical sections, photo image of location, any other documentation pertinent to request.

Appendix C2: Proposed Request for Design Exception Form (Annotated)

DEPARTMENT OF TRANSPORTATION

STATE OF GEORGIA

INTEROFFICE CORRESPONDENCE

REQUEST FOR DESIGN EXCEPTION (or VARIANCE)

FILE P.I. Number

Project Number (if available)

County

Project Description

OFFICE Design Office

DATE Date

FROM Office Head (GDOT Submitting Office, otherwise engineering firm letterhead)

TO State Design Policy Engineer

SUBJECT Request for Design Exception (or Variance) for (list criteria here) ex: Shoulder Width Approval of a Design Exception (or Variance) is requested for this project.

PROJECT DESCRIPTION Provide a general description of the project including the length of the project, the general location of the project including any city and county limits or proximity thereto, speed design, posted speed limit, and describe the proposed typical sections and other major improvements to be constructed.

DESIGN EXCEPTION/VARIANCE[1] List design exception or design variance type proposed

FEATURE(S) REQUIRING A DESIGN EXCEPTION/VARIANCE Describe the feature(s) requiring a design exception or a design variance. Give the values of the current standard criteria and the values that are proposed to be used. Include the latitude and longitude of the beginning and ending point(s) of the design exception.[2]

CURRENT AND FUTURE TRAFFIC DATA Describe current and future traffic volumes with any other pertinent traffic data.

CRASH DATA/ SUBSTANTIVE SAFETY RISK[3] Describe the crash history within the project limits for the last three years.[4] In particular, address and summarize the crash type history related to the design exception

[1] None of the Design Exception reports examined for this study included the DE criteria unless it was written in by hand later.

[2] Many of the submitted DE reports did not include beginning and ending mile points for the design feature. Latitude and Longitude information will assist in recovering data from the crash database.

[3] “When faced with decisions to incorporate one or more design exceptions, the designer should reflect on whether the design exception will influence substantive safety, and if so to what extent. In other

or variance type under request.[5] Include the latitude and longitude of the beginning and ending point(s) of the roadway that may be impacted by the design exception.

WHY THE CURRENT STANDARD CRITERIA CANNOT BE MET Summarize why the current AASHTO Standard Controlling Criteria (Design Exception)/GDOT Standard Criteria (Design Variance) cannot be met.

COST TO MEET STANDARD CRITERIA Summarize the cost estimate for construction and right-of-way and other associated costs for constructing or reconstructing the design feature to meet current standards.

MITIGATION PROPOSED Describe any mitigation proposed to lessen the impact of not meeting current standard criteria. (FHWA publication Mitigation Strategies for Design Exceptions is a good reference) If mitigation or other additional enhancement costs are significant, summarize these costs at this point.

RECOMMENDATION The Engineer/Designer of Record must make a recommendation to the approving authority for action. Any conditions to the approval of this exception should be clearly stated. Include name and contact number.

The signature block for approval will take one or the other of the following forms:

For projects NOT classified as Full Oversight (FOS) or Project of Division Interest (PoDI):
Recommend: (Include this line for consultant designed projects only)________________

Engineer of Record Date

Concur:____

GDOT Director of Engineering Date

Approve:____

GDOT Chief Engineer Date

For projects classified as Full Oversight (FOS) or Project of Division Interest (PoDI):

____

words, if a design exception is to be used, the designer should seek the best information available that characterizes the long-term substantive safety risk of that exception (frequency, type, and severity of crashes). The following are basic questions designers should ask when contemplating a design exception: (1) If this is an existing location and a design exception is being studied, how good (or poor) is the existing substantive safety performance? (2) If this is new construction or reconstruction and a design exception is being studied, what should the long-term safety performance of the roadway be? (3) Given the specifics of the design exception (geometric element, degree/magnitude of the variance, length of highway over which it is applied, traffic volume, etc.), what is the difference in expected substantive safety if the exception is implemented?" pg. 10
http://safety.fhwa.dot.gov/geometric/pubs/mitigationstrategies/fhwa_sa_07011.pdf

[4] FDOT required the last five years of crash data and analysis using HSM CRFs. http://www.dot.state.fl.us/officeofdesign/Training/DesignExpo/2014/presentations/GerrellBenjamin-DesignExceptionandVariations.pdf

[5] Relating Crash Type to Design Exception Type

Recommend: (Include this line for consultant designed projects only)________________

Engineer of Record Date

Concur:____

GDOT Director of Engineering Date

Approve:____

GDOT Chief Engineer Date

Approve:____

FHWA Division Administrator Date

Required attachments: plan/profile sheets

Other attachments: Location sketch, typical sections, photo image of location, any other documentation pertinent to request.

Appendix D: SPFs for Choosing Initial Screen Threshold

Facility Type	SPF	
Rural two-lane, two-way roadways	$N = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$ (all collisions)	
Rural multilane undivided roadways	$N = e^{(-9.653+1.176\times\ln(AADT)+\ln(L))}$ (all collisions)	
Rural multilane divided roadways	$N = e^{(-9.025+1.049\times\ln(AADT)+\ln(L))}$ (all collisions)	
Urban or suburban two-lane undivided arterials	$N = exp^{(-15.22+1.68\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-5.47+0.56\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Urban or suburban three-lane arterials including a center two-way left-turn lane	$N = exp^{(-12.40+1.41\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-5.74+0.54\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Urban or suburban four-lane undivided arterials	$N = exp^{(-11.63+1.33\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-7.99+0.81\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Urban or suburban four-lane divided arterials	$N = exp^{(-12.34+1.36\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-5.05+0.47\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Urban or suburban five-lane arterials including a center two-way left turn lane	$N = exp^{(-9.70+1.17\times\ln(AADT)+\ln(L))}$ (multi-vehicle collisions)	$N = exp^{(-4.82+0.54\times\ln(AADT)+\ln(L))}$ (single-vehicle crashes)
Rural freeway segments, four lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Rural freeway segments, four lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Rural freeway segments, six lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)

Facility Type	SPF	
Rural freeway segments, six lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Rural freeway segments, six lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Rural freeway segments, six lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, four lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, four lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, six lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, six lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, eight lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, eight lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, ten lanes, fatality or injury	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)
Urban freeway segments, ten lanes, property damage	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (multi-vehicle collisions)	$N = L \times exp^{(a+b\times\ln[c\times AADT])}$ (single-vehicle crashes)

N = base total number of roadway segment crashes per year

AADT = average annual daily traffic volume (vehicles per day)

L = length of roadway segment (miles)

(American Association of State Highway and Transportation Officials, 2010b)

Rural two-lane and multilane roadways only require information on AADT and number of through lanes. However, urban and suburban arterials require AADT, number of through lanes, and number of vehicles involved in crash (multi-vehicle or single-vehicle). Rural freeway requires the same information as urban and suburban arterials; however, SPFs for rural freeways have different regression coefficients for four, six, and eight lanes. Urban freeways are similar to this requirement but include different regression coefficients for four, six, eight, and ten lanes. SPFs for speed change lanes and ramp entrance or exit were not included in the table due to the large variety of regression coefficients needed for a variety of conditions: urban or rural, multiple vehicle or single vehicle, one or two lanes, fatality/injury or property damage. More information about these SPFs can be found in the HSM Supplement (American Association of State Highway and Transportation Officials, 2010b).

Appendix E: Crash Types Potentially Associated with DE Types

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Design Speed	NA	NA	NA
Lane Width	Run-off-road	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Cross-median	Head-on	Manner of Collision
	Cross-centerline	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
	Sideswipe (same direction)	Sideswipe - same direction	Manner of Collision
	Rear-end crashes if operations deteriorate (abrupt speed reduction)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Collision with parked vehicle	Parked motor vehicle	First Harmful Event
	Head-on Collision	Head-on	Manner of Collision
		Wrong side of the road	Contributing Factors

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Shoulder Width	Run-off-road	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Cross-median	Head-on	Manner of Collision
	Cross-centerline	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
	Pavement edge drop-offs	Not a collision with a motor vehicle	Manner of Collision
		Other non-collision	First Harmful Event
	Rear-end crashes if operations deteriorate (abrupt speed reduction)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Sideswipe or head-on	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
		Sideswipe - same direction	Manner of Collision
	Overturn	Overturn	First Harmful Event
	Collision with parked vehicle	Parked motor vehicle	First Harmful Event

DE Type	Crash Type	Crash Table and Crash Report Terminology	Field
Bridge Width	Collision with bridge rail or approach guardrail	Bridge pier/ abutment	First Harmful Event
		Bridge parapet end	First Harmful Event
		Bridge rail	First Harmful Event
		Guardrail face	First Harmful Event
		Impact attenuator	First Harmful Event
	Rear-end crashes (abrupt speed reduction)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Cross-centerline crashes	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Horizontal Alignment	Run-off-road	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Cross-median	Head-on	Manner of Collision
	Cross-centerline	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
	Large vehicle rollover	Overturn	First Harmful Event
	Skidding	Weather conditions	Contributing Factors
		Driver lost control	Contributing Factors
		Too fast for conditions	Contributing Factors
	Rear-end crashes if operations deteriorate (abrupt speed reduction)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Train-vehicle collision at sharp crossing angle	Railway train	First Harmful Event
	Unknown	Other	Contributing Factors
		Blank cell	Contributing Factors

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Super-elevation	Run-off-road	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Cross-median	Head-on	Manner of Collision
	Cross-centerline	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
	Large vehicle rollover	Overturn	First Harmful Event
	Skidding	Weather conditions	Contributing Factors
		Driver lost control	Contributing Factors
		Too fast for conditions	Contributing Factors
		Jackknife	Contributing Factors

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	**Field**
Super-elevation (continued)	Collision with fixed object	Not a collision with a motor vehicle	Manner of Collision
		Impact attenuator	First Harmful Event
		Bridge pier/ abutment	First Harmful Event
		Bridge parapet end	First Harmful Event
		Bridge rail	First Harmful Event
		Guardrail face	First Harmful Event
		Guardrail end	First Harmful Event
		Median Barrier	First Harmful Event
		Highway traffic sign post	First Harmful Event
		Overhead sign support	First Harmful Event
		Luminaire/ Light support	First Harmful Event
		Utility pole	First Harmful Event
		Other post	First Harmful Event
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Vertical Alignment	Refer to the sections on grade and stopping sight distance for more information on vertical alignment		
Grade	Run-off-road crashes	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Rear-end crashes descending grade or at signalized or unsignalized intersection	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Rear-end crashes at signalized or unsignalized intersection	Rear End	Manner of Collision
		Following too close, other	Contributing Factors

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Grade (continued)	Collision with fixed object	Not a collision with a motor vehicle	Manner of Collision
		Impact attenuator	First Harmful Event
		Bridge pier/ abutment	First Harmful Event
		Bridge parapet end	First Harmful Event
		Bridge rail	First Harmful Event
		Guardrail face	First Harmful Event
		Guardrail end	First Harmful Event
		Median Barrier	First Harmful Event
		Highway traffic sign post	First Harmful Event
		Overhead sign support	First Harmful Event
		Luminaire/Light support	First Harmful Event
		Utility pole	First Harmful Event
		Other post	First Harmful Event
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Train-vehicle collision	Railway train	First Harmful Event
	Sideswipe or head-on	Head-on	Manner of Collision
		Sideswipe - opposite direction	Manner of Collision
		Sideswipe - same direction	Manner of Collision

DE Type	Crash Type	Crash Table and Crash Report	
		Terminology	Field
Stopping Sight Distance	Collisions with vehicles stopped or slowed on the roadway	Rear End	Manner of Collision
		Other object (not fixed)	First Harmful Event
		Following too close, other	Contributing Factors
		Stopped	Maneuver Vehicle
	Collisions with objects in the roadway	Not a collision with a motor vehicle	Manner of Collision
		Other object (not fixed)	First Harmful Event
		Animal	First Harmful Event
		Deer	First Harmful Event
		Object or animal	Contributing Factors
	Collisions with vehicles entering from intersecting roadways or driveways	Angle	Manner of Collision
		Failed to yield	Contributing Factors
		Disregard stop sign/ signal	Contributing Factors
		No signal/ improper signal	Contributing Factors
		Too fast for conditions	Contributing Factors
		Distracted	Contributing Factors
	Pedestrian-vehicle due to restricted sight distance	Not a collision with a motor vehicle	Manner of Collision
		Pedestrian	First Harmful Event
	Bicycle-vehicle due to restricted sight distance	Not a collision with a motor vehicle	Manner of Collision
		Pedalcycle	First Harmful Event
	Right angle at signalized or unsignalized intersection	Angle	Manner of Collision
		Failed to yield	Contributing Factors
		Improper turn	Contributing Factors
		Misjudged clearance	Contributing Factors
		Too fast for conditions	Contributing Factors
	Left-turn head-on	Head-on	Manner of Collision
		Turning left	Maneuver Vehicle
		Failed to yield	Contributing Factors
		Improper turn	Contributing Factors
		Misjudged clearance	Contributing Factors
		Too fast for conditions	Contributing Factors

DE Type	Crash Type	Crash Table and Crash Report Terminology	Field
Cross Slope	Run-off-road crashes	Not a collision with a motor vehicle	Manner of Collision
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Loss of control when crossing over a high cross-slope break	Driver lost control	Contributing Factors
	Rear-end crashes at signalized or unsignalized intersection	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
	Collision with a fixed object	Not a collision with a motor vehicle	Manner of Collision
		Impact attenuator	First Harmful Event
		Bridge pier/ abutment	First Harmful Event
		Bridge parapet end	First Harmful Event
		Bridge rail	First Harmful Event
		Guardrail face	First Harmful Event
		Guardrail end	First Harmful Event
		Median Barrier	First Harmful Event
		Highway traffic sign post	First Harmful Event
		Overhead sign support	First Harmful Event
		Luminaire/ Light support	First Harmful Event
		Utility pole	First Harmful Event
		Other post	First Harmful Event
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
	Train-vehicle collision	Railway train	First Harmful Event

DE Type	Crash Type	Crash Table and Crash Report Terminology	Field
Vertical Clearance	Collision with overhead structure	Misjudged clearance	Contributing Factors
		Other fixed object	First Harmful Event
		Not a collision with a motor vehicle	Manner of Collision
	Rear-end crashes (vehicles following the vehicle that collided with the structure)	Rear End	Manner of Collision
		Following too close, other	Contributing Factors
Horizontal Clearance	Collision with fixed object too close to road	Not a collision with a motor vehicle	Manner of Collision
		Impact attenuator	First Harmful Event
		Bridge pier/abutment	First Harmful Event
		Bridge parapet end	First Harmful Event
		Bridge rail	First Harmful Event
		Guardrail face	First Harmful Event
		Guardrail end	First Harmful Event
		Median Barrier	First Harmful Event
		Highway traffic sign post	First Harmful Event
		Overhead sign support	First Harmful Event
		Luminaire/Light support	First Harmful Event
		Utility pole	First Harmful Event
		Other post	First Harmful Event
		Culvert	First Harmful Event
		Curb	First Harmful Event
		Ditch	First Harmful Event
		Embankment	First Harmful Event
		Fence	First Harmful Event
		Mailbox	First Harmful Event
		Tree	First Harmful Event
		Other fixed object	First Harmful Event
Structural Capacity	NA		

(Federal Highway Administration, 2007c), (American Association of State Highway and Transportation Officials, 2010b), (Indiana Department of Transportation, 2013), (Schroeder, Cunningham, Findley, Hummer, & Foyle, 2010)

Appendix F: Hypothesis Test Code

```
# install the packages first if you don't have any of them below
library(glmnet), library(AER), library(MASS), library(mdscore), library(glmnet)

# load data first, set your working directory and make sure you don't change the header of the data
# x is the before, y is the after, and xy is the combined data
setwd("C:\\Users\\YINGPING ZHAO\\Desktop")
dex <- read.csv("datax.csv",header=T)
dey <- read.csv("datay.csv",header=T)
dexy <- read.csv("dataxy.csv",header=T)

# here is the NB module used for the maximum log likelihood
fitNB <- function(X) {
  n <- length(X)
  loglik.conc <- function(r) {
    prob <- n*r / (sum(X) + n*r)
    sum( lgamma(r + X) - lgamma(r) - lgamma(X + 1) +
           r * log(prob) + X * log(1 - prob) )
  }

  res <- optimize(f = loglik.conc, interval = c(0.001, 1000),
                  maximum = TRUE)
  r <- res$maximum[1]
  params <- c(size = r, prob = n*r / (sum(X) + n*r))
  attr(params, "logLik") <- res$objective[1]
  params
}
## compute score vector and info matrix at params 'psi' using closed forms
scoreAndInfo <- function(psi, X) {
  size <- psi[1]; prob <- psi[2]
  n <- length(X)
  U <- c(sum(digamma(size + X) - digamma(size) + log(prob)),
       sum(size / prob - X / (1-prob) ))
  I <- matrix(c(- sum(trigamma(size + X) - trigamma(size)),
              -n / prob, -n / prob,
              sum( size / prob^2  + X / (1-prob)^2)),
            nrow = 2, ncol = 2)
  names(U) <- rownames(I) <- colnames(I) <- c("size", "prob")
  LM <-  as.numeric(t(U) %*% solve(I) %*% U)
  list(score = U, info = I, LM = LM)
}
## continuing on the question code a is for "all" & fit all the 3 models for x, y and xy.
c.fit <- fitNB(X = dex)
w.fit <- fitNB(X = dey)
a.fit <- fitNB(X = dexy)

## use restricted parameter estimate to compute the LM(Score) test result
c.sI <- scoreAndInfo(psi = a.fit, X = dex)
w.sI <- scoreAndInfo(psi = a.fit, X = dey)
```

```
D.LM <- c.sI$LM + w.sI$LM
p.LM <- pchisq(D.LM, df = 1, lower.tail = F)
# this is the one-sided result for p and degree of freedom for this test is 1
p.LM
```

Appendix G: Georgia Uniform Motor Vehicle Accident Report

GEORGIA UNIFORM MOTOR VEHICLE ACCIDENT REPORT

Accident Number 1 | Agency NCIC No. 2 | County 3 | Date Rec. by DOT 4

Date 5 | Day of Week 6 ☐ Sun ☐ M ☐ T ☐ W ☐ Th ☐ F ☐ S | Time 7 | Off. Arrived 8 | Total Number of: 9 Vehicles | Injuries | Fatalities | Inside City Of: 10

Road of Occurrence ____11____
1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 ☐ Co. Road 4 ☐ City St.

At Its Intersection With ____12____
1 ☐ 2 ☐ Lowest St. Rt. 3 ☐ Co. Road 4 ☐ City St.

Not At Its Intersection But_____13____ ☐ Miles ☐ Feet 1 ☐ North 2 ☐ South 3 ☐ East 4 ☐ West Of:__________14
1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 ☐ Co. Road 4 ☐ city St. 5 ☐ Co. Line

And continuing in the direction checked above, the Next Reference Point is ____15____
1 ☐ Interstate 2 ☐ Lowest St. Rt. 3 ☐ Co. Road 4 ☐ City St. 5 ☐ Co. Line

Corrected Report? Yes ☐ 16
Suppl. To Original? Yes ☐
Hit and Run ? Yes ☐ 17

Driver # 18 / Ped # ☐ — 19 LAST NAME, FIRST, MIDDLE; Address 20	Driver # / Ped # ☐ — LAST NAME, FIRST, MIDDLE; Address
City, State, Zip, DOB 21	City, State, Zip, DOB
22 Driver's License No., 23 Class, 24 State, 25 ☐ Male ☐ Female	Driver's License No., Class, State, ☐ Male ☐ Female
Posted Speed 26, Insurance Co. 27, Policy No. 28	Posted Speed, Insurance Co., Policy No.
Year 29, Make 30, Model 31, Telephone No. 32	Year, Make, Model, Telephone No.
VIN 33, Vehicle Color 34	VIN, Vehicle Color
Tag # 35, State, County, Year	Tag #, State, County, Year
Trailer Tag # 36, State, County, Year	Trailer Tag #, State, County, Year
37 ☐ Same as Driver, Owner's Last Name, First, Middle	☐ Same as Driver, Owner's Last Name, First, Middle
Address	Address
City, State, Zip	City, State, Zip
38 Removed By, 39 ☐ Request, 40 ☐ List	Removed By, ☐ Request, ☐ List
Alcohol Test 41, Type, Results 42, Drug Test 43, Type, Results 44	Alcohol Test, Type, Results, Drug Test, Type, Results
Driver Cond 45, Direction Of Travel 46, Vision Obscured 47, Contributing Factors ____51____	Driver Cond, Direction Of Travel, Vision Obscured, Contributing Factors
48 Veh Cond, 49 Veh Maneuver, Ped. Maneuver 50	Veh Cond, Veh Maneuver, Ped. Maneuver
Most Harmful Event 52, Veh Class: 53, Veh Type: 54	Most Harmful Event, Veh Class:, Veh Type:
Traffic Ctrl 55, 56 Device Inoperative? ☐ Yes ☐ No	Traffic Ctrl, Device Inoperative? ☐ Yes ☐ No

Injured Taken To: 57 By:

58 EMS Notified Time | EMS Arrival Time | Hospital Arrival Time | 59 Photos Taken: ☐Yes ☐No | By:

60 Report By: | Department | Report Date | 61 Checked By: | Date Checked

62 Witness(es): Name | Address | City | State | Zip Code | Telephone No.

63 DOT MICROFILM NUMBER (DO NOT WRITE IN THIS SPACE)

COMMERCIAL VEHICLES ONLY

Carrier Name 64; Vehicle # 65	Carrier Name; Vehicle #
66 Address, State, Zip	Address, State, Zip
No. of Axles 67, G.V.W.R. 68, 69 Fed. Reportable 1 ☐ Yes 2 ☐ No, Cargo Body Type 70	No. of Axles, G.V.W.R., Fed. Reportable 1 ☐ Yes 2 ☐ No, Cargo Body Type
Vehicle Config. 71, I.C.C.M.C. # 72, U.S. D.O.T. # 73, Interstate ☐ Intrastate ☐ 74	Vehicle Config., I.C.C.M.C. #, U.S. D.O.T. #, Interstate ☐ Intrastate ☐
75 C.D.L.? 1 ☐ Yes 2 ☐ No 76 C. D.L. Suspended? 1 ☐ Yes 2 ☐No	C.D.L.? 1 ☐ Yes 2 ☐ No C.D.L. Suspended? 1 ☐ Yes 2 ☐ No
77 Vehicle Placarded? 1 ☐ Yes 2 ☐ No 78 Hazardous Materials? 1☐ Yes 2☐No	Vehicle Placarded? 1 ☐ Yes 2 ☐ No Hazardous Materials? 1 ☐ Yes 2 ☐ No
79 Released? 1 ☐ Yes 2 ☐ No	Released? 1 ☐ Yes 2 ☐ No
If YES, Name or 4 Digit Number from Diamond or Box: ____80____	If YES, Name or 4 Digit Number from Diamond or Box: ________
1 Digit Number from Bottom of Diamond: ___81___	1 Digit Number from Bottom of Diamond: ________
__ Ran Off Road __ Down Hill Runaway __ Cargo Loss or Shift __ Separation of Units	__ Ran Off Road __ Down Hill Runaway __ Cargo Loss or Shift __ Separation of Units

REMARKS 82

INDICATE ON THIS DIAGRAM WHAT HAPPENED
84

INDICATE NORTH

CITATIONS – VEHICLE # _________85	CITATIONS – VEHICLE # _________

First Harmful Event 86	Traffic-Way Flow 87	Weather 88	Surface Cond. 89	Light Cond. 90	Manner Of Collision 91	Location At Area Of Impact 92	Road Comp. 93	Road Def. 94	Road Character 95A	Construction/Maintenance Zone 95B

96	VEH #_______	VEH# _____
97 Number of Occupants		
98 Point of Initial Contact		
99 Damage To Vehicles		

100 SKID DISTANCE BEFORE IMPACT ___________ VEH. AFTER __________ VEH. Width of Road

___________ VEH. ___________ VEH. _______101_______

Damage Other Than Vehicle: 102	Owner:						AGE	SEX	VEH #	POS	INJURY	TAKEN FOR TREAT	EJECT	SAFETY EQUIP	EXTRIC	AIR BAG
Occupants 103	Driver # Or Pedestrian #															
	Driver # Or Pedestrian #															
LAST NAME	FIRST	ADDRESS	CITY	STATE	ZIP		X	X	X	X	XXXXX	XXXXX	XXXX	XXXXX	XXXXX	XXXX

MAIL TO: Georgia Department of Transportation, ACCIDENT REPORTING UNIT, P.O. BOX 80447, CONYERS, GA 30013-8447

Codes and conditions used for completing the 'front' of the Accident Report.

ALCOHOL AND/OR DRUG TEST GIVEN
1 - Yes 2 - No 3 - Refused

TYPE TEST
1 - Blood 2 - Breath 3 - Urine 4 - Other

DRIVER CONDITION
1 - Not Drinking
2 - Not Known if U.I.
3 - Drinking Not Impaired
4 - U.I. Alcohol
5 - U.I. Drugs
6 - U.I.Alcohol & Drugs
7 - Physical Impairment
8 - Apparently Fell Asleep

DIRECTION OF TRAVEL
1 - North 2 - South 3 - East 4 - West

VISION OBSCURED BY
1 - Not Obscured
2 - Headlights
3 - Sunlight
4 - Parked Vehicle
5 - Trees, Bushes
6 - Rain, Snow, Ice on Windshield
7 - Other

VEHICLE CONDITION
1 - No Known Defects
2 - Tire Failure
3 - Brake Failure
4 - Improper Lights
5 - Steering Failure
6 - Slick Tires
7 - Other

VEHICLE MANEUVER
1 - Turning Left
2 - Turning Right
3 - Making U-turn
4 - Stopped
5 - Straight
6 - Changing Lanes
7 - Backing
8 - Parked
9 - Passing
10 - Negotiating A Curve
11 - Entering/Leaving Parking
12 - Entering/Leaving Driveway

PEDESTRIAN MANEUVER
1 - Crossing, Not At Crosswalk
2 - Crossing at Crosswalk
3 - Walking with Traffic
4 - Walking Against Traffic
5 - Pushing Or Working on Vehicle
6 - Other Working in Road
7 - Playing Roadway
8 - Standing in Roadway
9 - Off Roadway
10 -Other
11 -Darting Into Traffic

FIRST HARMFUL EVENT/MOST HARMFUL EVENT NON-COLLISION
1 - Overturn
2 - Fire/Explosion
3 - Immersion
4 - Jackknife
5 - Other Non-Collision

COLLISION WITH OBJECT NOT FIXED
6 - Pedestrian
7 - Pedalcycle
8 - Railway Train
9 - Animal
10 - Parked Motor Vehicle
11 - Motor Vehicle In Motion
12 - Motor Vehicle In Motion - In Other Roadway
13 - Other Object (Not Fixed)
14 - Deer

COLLISION WITH FIXED OBJECT
15 - Impact Attenuate
16 - Bridge Pier/Abutment
17 - Bridge Parapet End
18 - Bridge Rail
19 - Guardrail Face
20 - Guardrail End
21 - Median Barrier
22 - Highway Traffic Sign Post
23 - Overhead Sign Support
24 - Luminaire light Support
25 - Utility Pole
26 - Other Post
27 - Culvert
28 - Curb
29 - Ditch
30 - Embankment
31 - Fence
32 - Mailbox
33 - Tree
34 - Other - Fixed Object

CONTRIBUTING FACTORS
1 - No Contributing Factors
2 - D.U.I.
3 - Following Too Close
4 - Failed to Yield
5 - Exceeding Speed Limit
6 - Disregard Stop Sign/Signal
7 - Wrong Side Of Road
8 - Weather Conditions
9 - Improper Passing
10 - Driver Lost Control
11 - Changed Lanes Improperly
12 - Object Or Animal
13 - Improper Turn
14 - Parked Improperly
15 - Mechanical Or Vehicle Failure
16 - Surface Defects
17 - Misjudged Clearance
18 - Improper Backing
19 - No Signal/Improper Signal
20 - Driver Condition
21 - Driver's Vehicle
22 - Too Fast For Conditions
23 - Improper Passing Of School Bus
24 - Disregard Police Officer
25 - Distracted
26 - Other
27 - Cell Phone
28 - Inattentive

VEHICLE CLASS
1 - Privately Owned
2 - Police
3 - Fire
4 - School
5 - Other Govt. Owned
6 - Military
7 - Commercial Vehicle (For Acc. Reporting Purposes Only)
8 - Other

VEHICLE TYPE
1 - Passenger Car
2 - Pickup Truck
3 - Truck Tractor (Bobtail)
4 - Tractor/Trailor
5 - Tractor W/Twin Trailers
6 - Logging Truck
7 - Logging Tractor/Trailer
8 - Single Unit Truck
9 - Panel Truck
10 - Van
11 - Utility Passenger Vehicle.
12 - Vehicle With Trailer
13 - Bus
14 - Truck Towing House Trailer
15 - Ambulance
16 - Motorized Recreational Vehicle
17 - Motorcycle, Scooter, Minibike
18 - Moped
19 - Pedalcycle, Bicycle
20 - Farm or Construction. Equip.
21 - All Terrain Vehicle
22 - Other
23 - Go cart

TRAFFIC CONTROL
0 - Gates
1 - No Control Present
2 - Traffic Signal
3 - RR Signal/Sign
4 - Warning Sign
5 - Stop Or Yield Sign
6 - No Passing Zone
7 - Lanes
8 - Other
9 - Flashing Lights

CARGO BODY TYPE
1 - Van (Encl. Box)
2 - Auto Carrier
3 - Bus
4 - Dump
5 - Garbage/Refuse
6 - Flatbed
7 - Cargo Tanker
8 - Concrete Mixer
9 - Other

VEHICLE CONFIGURATION
1 - Bus (Seating for More Than 15 Passengers)
2 - Single Unit Truck: 2 Axles
3 - Single Unit Truck: 3 or More Axles
4 - Truck Trailer
5 - Truck Tractor (Bobtail)
6 - Tractor Trailer
7 - Tractor With Twin Trailers
8 - Unknown Heavy Truck (Cannot Classify)

Codes and conditions used for completing the 'back' of the Accident

TRAFFIC-WAY FLOW
1 - Two-way Trafficway With No Physical Separation
2 - Two-way Trafficway With a Physical Separation
3 - Two-way Trafficway With a Physical Barrier
4 - One-way Trafficway
5 - Continuous Turning Lane

WEATHER
1 - Clear
2 - Cloudy
3 - Rain
4 - Snow
5 - Sleet
6 - Fog
7 - Other

SURFACE CONDITION
1 - Dry
2 - Wet
3 - Snowy
4 - Icy
5 - Other
6 - Mud
7 - Sand
8 - Slush
9 - Oil

LIGHT CONDITION
1 - Daylight
2 - Dusk
3 - Dawn
4 - Dark - Lighted
5 - Dark - Not Lighted

MANNER OF COLLISION
1 - Angle
2 - Head On
3 - Rear End
4 - Sideswipe - Same Direction
5 - Sideswipe - Opposite Direction
6 - Not A Collision With a Motor Vehicle

LOCATION AT AREA OF IMPACT
1 - On Roadway
2 - On Shoulder
3 - Off Roadway
4 - Median
5 - Ramp
6 - Gore

ROAD COMPOSITION
1 - Concrete
2 - Black Top
3 - Tar And Gravel
4 - Dirt
5 - Gravel
6 - Other

CONTRIBUTING ROAD DEFECTS
1- No Defects
2 - Defective Shoulders
3 - Holes, Deep Ruts, Bumps
4 - Loose Material On Surface
5 - Water Standing
6 - Road Under Construction
7 - Running Water
8 - Other

ROAD CHARACTER
1 - Straight And Level
2 - Straight On Grade
3 - Straight On Hillcrest
4 - Curve And Level
5 - Curve On Grade
6 - Curve On Hillcrest

DAMAGE TO VEHICLE
1 - None
2 - Slight
3 - Moderate
4 - Extensive
5 - Fire Present

AGE
00 - Up To One Year
01 - 97 Actual Age
98 - Ninety-eight Or Older
99 - Unknown

SEX
M - Male F - Female

TAKEN FOR TREATMENT
1 - Yes 2 - No

INJURY CODE
0 - Not injured
1 - Killed
2 - Serious
3 - Visible
4 - Complaint

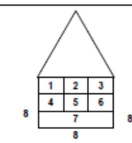
Construction / Maintenance Zone Codes
0 - None 1 - Construction 2 - Maintenance 3 - Utility 4 - Unknown Type

EJECTION
1 - Not Ejected
2 - Trapped
3 - Totally Ejected
4 - Partially Ejected

SAFETY EQUIPMENT
0 - None Used
1 - Shoulder Belt
2 - Lap Belt
3 - Lap and Shoulder Belt
4 - Child Safety Seat (Property Used)
5 - Child Safety Seat (Improperly Used)
6 - Motorcycle Helmet
7 Bicycle Helmet
8 - Unknown

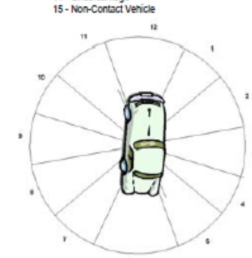
EXTRICATION (Equipment Used)
1 - Yes 2 - No

AIR BAG FUNCTION
0 - No Air Bag In This Seat
1 - Deployed Air Bag
2 - Non-Deployed Air Bag
3 - Deployed Side
4 - Deployed other Directions
5 - Deployed Multiple Directions
6 - Non-Deployed Front
7 - Non-Deployed Side
8 - Non-Deployed Other Direction
9 - Non-Deployed Multiple Direction



SEATING POSITION

POINTS OF INITIAL CONTACT
00 - Overturned
13 - Top
14 - Undercarriage
15 - Non-Contact Vehicle



Page ____ of ____

Accident Number	Agency NCIC	Accident Date	Georgia Uniform Motor Vehicle Report Continuation

OCCUPANTS

LAST NAME	FIRST	ADDRESS	CITY	STATE	ZIP	AGE	SEX	VEH #	POS	INJURY	TAKEN FOR TREAT	EJECT	SAFETY EQUIP	EXTRIC	AIR BAG

Injured Taken To: **By:**

Witness – Name **Address:**

Phone:

Additional Remarks

Reported By:

Sample **Continuation** page

Appendix H: Criteria from Georgia Uniform Vehicle Accident Report used in Case Study Analysis

Criteria	Description
Posted Speed	Posted speed limit for the road on which the vehicle was traveling. If speeding or too fast for conditions is marked as a contributing factor, must be explained in the remarks section.
Driver Condition	If it was determined (test results) that the driver or pedestrian was under the influence of alcohol or drugs, the appropriate code is entered on the Supplement under driver condition and contributing factor (Item #45 and #51).
Direction of Travel	The direction of travel prior to the accident.
	The direction of travel prior to the turn is recorded if the vehicle was making a turn.
Vision Obscured	See Overlay for available codes.
Vehicle Maneuver	The action the driver was taking at the time of the collision.
Pedestrian Maneuver	The action the pedestrian was taking at the time of the collision.
Contributing Factors	The code factor(s) that most contributed to the cause of the accident. See the Overlay for available codes.
Most Harmful Event	The event that causes the most severe injury or, if there is no injury, the worst degree of damage. Applies to each vehicle. See Overlay for available codes.
Vehicle Class	See Overlay for available codes.
Vehicle Type	See Overlay for available codes.
Traffic Control	Record the traffic control that was most prominent at the point of impact. See Overlay for available codes.
Device Inoperative?	Yes = control is inoperative No = control is operative

Criteria	**Description**
Remarks	Detailed remarks that clarify any part of the report
INDICATE ON THIS DIAGRAM WHAT HAPPENED	Draw a diagram for all reports.
INDICATE ON THIS DIAGRAM WHAT HAPPENED	Record north by drawing an arrow within the circle located in the upper right hand corner of the diagram area.
Citations – Vehicle #	Number each vehicle to correspond with the number assigned on the front of the report (item 17).
	Draw a solid arrow to indicate the direction from which the vehicle came.
	Draw a broken line to indicate from the area of impact to where the vehicles came to rest.
	A second area of impact should be identified by a small arrow labeled 2nd area of impact.
	Include and identify in the diagram any physical features of importance such as an obstruction to the drivers' view, traffic signal/sign, fixed objects, debris, and vehicle parts on scene and so on.
	If the vehicles have been moved, and for some reason the officer's investigation cannot determine the path of travel, a diagram of the roadway should still be drawn with the obstructions, debris from accident, traffic signal/sign, and so on.
	If you have deer/animal accidents with no other involvement (single vehicle and no injury or fatality), then a diagram is optional.
	If a road character is marked curve, the diagram should show a curve.
	If the road character is marked straight, the diagram should show a straight roadway.
	Record the vehicle #. Officers must record a Georgia code for all violations. For example, Speeding (40-6-181). If more room is needed, use the Remarks section.
Citations – Vehicle #	Record the vehicle #. Officers must record a Georgia code for all violations. For example, Speeding (40-6-181). If more room is needed, use the Remarks section.

Criteria	Description
First Harmful Event	See the front Overlay for valid codes. This information provides major clues as to how the accident occurred. First harmful event applies to the first injury or damage producing event. Record only (1) one code. Every accident must have a code.
Weather	See the Overlay for valid codes. Record the most prominent weather condition at the time of the accident.
Surface Cond.	See the Overlay for valid codes. Record the most prominent surface condition at the time of the accident.
Light Conditions	See the Overlay for valid codes. Code the light condition at the time of the accident, which may not be the same as the time of investigation.
Manner of Collision	How the vehicles initially made contact. The identification in an accident of how the vehicles initially came together.
Manner of Collision	Angle Accidents: Applies when a collision results from the FIRST injury or damage producing event involves two or more motor vehicles traveling in directions that are generally perpendicular.
	Rear End: Applies when the FIRST injury or damage-producing event involves two motor vehicles proceeding in the same general direction.
	Head-on Collision: A collision in which the front-end of one vehicle collides with the frontend of another, while the two vehicles are traveling in opposite directions.
	Sideswipe – Same Direction: Applies when the FIRST injury or damage-producing event involves two motor vehicles colliding side to side while proceeding in the same direction.
	Sideswipe – Opposite Direction: Applies when the FIRST injury or damage-producing event involves two motor vehicles colliding side to side from generally considered opposite directions.
	Not a collision with a Motor Vehicle: Applies when the FIRST occurrence doing injury or damage involves a motor vehicle that does not involve a collision, overturning, or pedestrian.
Location at Area of Impact	See the Overlay for valid codes.

Criteria	Description
Point of Initial Contact	See the Overlay for valid codes. Code the initial point of impact for each vehicle using the 12-point clock:
Point of Initial Contact	Use code 00 for overturn
Damage to Vehicles	Use code 13 for the top of vehicle
	Use code 14 for the undercarriage.
	See the Overlay for valid codes. Determine the damage severity and record the correct code.
Damage Other Than Vehicle	Record any property damage that resulted from the accident, other than the vehicles involved.
Occupants	Give injured parties an injury code of 2, 3, or 4. Give uninjured parties a code of zero (0). See the Overlay for valid codes. Give fatalities a code of one (1).
Occupants	Include the number of complaints of injury (code 4) with the number of injuries listed on the top front of the report (item #9). These numbers should match.
	Taken for treatment applies to injured parties taken from the scene of an accident by any means to a medical facility for treatment. If a victim dies in route to a hospital, record code 1 for yes. If a victim is dead on the scene and is transported to be pronounced dead, record code 2 for no.