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Modeling Roadside Safety Hazards to Predict Annual Crash Cost to Encroaching Vehicles in Rural Road Networks

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Modeling Roadside Safety Hazards to Predict Annual Crash Costs to Encroaching Vehicles in Rural Road Networks

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
Department of Civil and Environmental Engineering
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DEDICATION

I dedicate my reaching of this milestone to my wife Maritza whose love and daily encouragement kept me going through the years. To my children Paola, Pamela, Isidro and Ignacio, who supported me in the initial decision and who had lived their lives in such manner as to allow me free time to complete this endeavor. To my mother, Vilma, for being my first teacher, therefore launching me in the quest for learning.

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Above all, I give all credit and gratitude to my Lord and Savior Jesus Christ who loved me and gave His life in the cross to pay for my sins *("tetelestai")* so that I, as a believer—and you if you choose so—, could have eternal life which is to know Him and our Heavenly Father.

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ABSTRACT

Roadside crashes account for a large portion of total fatal crashes that occur annually in the United States. About 30% of those fatalities are the result of single vehicle run-off-road crashes. A large proportion of these fatal crashes occur in rural roads when vehicles depart from the travel lane and collide with trees or other roadside safety hazards. Many of these run-off-road accidents occur in local roads that carry traffic volumes between 1,000 and 20,000 vehicles per day. Many of these roads are part of the jurisdiction of county authorities faced with the dilemma of having too many "potentially dangerous" sites and lacking a methodology for assessing their risk to rank them accordingly; and to apply the limited resources to the ones that will bring the greatest benefit to society. This situation describes the case in Hillsborough County, Florida, in 2004 when they contracted a study with the Transportation Program of the Department of Civil and Environmental Engineering of the University of South Florida. The initial scope was to develop a methodology to assess the potential risk for each of 19 sites in a given list to prioritize further studies. The project was sponsored by the Engineering Division, Public Works Department, of Hillsborough County. The methodology developed considered the roadside safety hazards at each location and it was based on the use of the Road Safety Analysis Program (RSAP) software distributed as part of the 2002 AASHTO's Roadside Design Guide. This dissertation presents a further development of this approach: it continues to use the probabilistic approach built into RSAP to calculate the annual crash cost of each roadside safety hazard at 45 study segments. It then obtains regression models to predict that annual crash cost, as computed by RSAP, based on roadway and traffic characteristics as well as on the nature, location and physical dimensions of the roadside safety hazard. For each study segment, the annual crash cost of each feature (as estimated with the models developed) is added for a final comparison with the RSAP Annual Crash Cost. A coefficient of determination (R^2) of 0.80 was obtained. The models developed were finally used to replicate the original 2005 study for Hillsborough County. Although there were minor variations on the risk index originally computed, the ranking of the 19 study sites remained basically the same with a clear cut indication of the sites that should be considered for further engineering studies.

CHAPTER 1: INTRODUCTION

1.1 Roadside Safety and the Roadside Environment

In the United States single vehicle run-off-the-road crashes account for almost one in every three highway fatalities. Even though the most desirable solution would be to keep all the vehicles on the road, vehicles will continue to leave the traveled way for a variety of compounding factors that includes the driver, the vehicle, traffic conditions, road geometry, etc. Therefore, the main focus of roadside safety is twofold: to keep vehicles from leaving the traveled lane, and to reduce the severity of the crashes in the event of a vehicle running off the road.

The roadside is often a very diverse environment having a wide array of objects; consequently, the types of objects involved in roadside fatalities are extensive. In some cases, the highway community has been able to successfully remove certain roadside objects, like the advertising signs removed from the right-of-way of interstate highways in the 1970’s. But removing all roadside objects is almost impossible. In cases where obstacles cannot be removed, they should be protected or made breakaway to dissipate the energy of the crash to reduce the injury severity.

Guardrail installation is one alternative implemented in order to protect vehicles from crashing with rigid objects on the roadside and to prevent errant vehicles from encountering non-traversable slopes. Guardrails come in many sizes, designs and shapes. The choice of appropriate guardrails is a function of many factors such as type of roadway facility, traffic volume, traffic mix, speed of traffic, proximity of the guardrail to the roadway, etc.

However, the installation of guardrail on all roads is not possible mainly due to budgetary constraints on highway expenditures. Moreover, and this is particularly true for existing rural roads, the characteristics of the available right-of-way may require additional investments to build up embankments and to solve additional and conflicting drainage conditions. On the other hand, the guardrail itself becomes a new object of the roadside environment that might be struck by an errant vehicle.

Consequently, for each site being considered in a guardrail retrofitting program, or any other roadside safety improvement project, it is necessary to assess the risk of the existing condition and to compare it with that of alternative layout improvements, including solutions involving placement of guardrail.

This is a sound and proven approach to evaluate a given site or location once it has been identified as dangerous. This is the project level analysis. However, how do we select such project? How do we choose among competing locations? These questions are usually addressed at the system planning level through some kind of network screening technique. It is what the Highway Safety Manual (*1*) identifies as the Roadway Safety Management Process.

From a roadside safety standpoint, this system-wide planning will allow for improved allocation of available funds. More importantly, it can deliver the tools to make the case to request additional funding to provide safer roads, at least for errand vehicles that run off the road. Therefore, there is a need for a methodology to conduct these studies at the road network level to prioritize the sites that require our utmost attention from a roadside safety perspective, assisting in the identification of sites where detailed studies at the project level should be conducted, including those for the installation of guardrails on rural roadways.

1.2 Prior Experience in the Hillsborough County Project

In 2004 there was no established methodology to assess the potential risk of run-off-the-road accidents on the Hillsborough County road network. The Engineering Division kept a log of the most dangerous locations based on public complaints and requests, most of them based on recent accidents. Those involving fatalities receive a higher level of attention.

Once a site had been identified, it was subjected to an engineering study which involved crash history review, site visits and definition of alternative solutions, some of which might involve guardrail placement. Cost estimates were prepared for a reduced set of solutions. A final solution was then selected and fit within the available budget for either the current or the following year.

That procedure worked well in practice. It was based on available manpower, local knowledge, engineering judgment, and prior successful design experiences. Moreover, the number of sites investigated typically exceeded the number of projects that could be accommodated within the available or projected budget. However, the procedure as implemented did not allow for any comparison between sites to obtain the greatest benefit for the money spent. Moreover, it was a reactive approach that did not have any system level planning procedure built into it that could be used to request or justify budgetary increments for roadside safety.

This reactive procedure was not typical in the County. Over the last several years, Hillsborough County had been improving many of its planning procedures to establish work programs to address the needs of the population. Examples of these programs were the Sidewalk Improvement Program and the Intersection Improvement Projects. Within this framework, there was a felt need to develop a procedure to prioritize the investments in roadside safety of the county road network. The idea was originally conceived as a methodology for prioritizing the installation of guardrails to improve the allocation of existing funding.

The county had a backlog of at least twenty sites that had been already identified as potential candidates for a more detailed study. However, it was known that only a handful of those could actually be undertaken under existing and projected budgets. There was also a desire to learn what the current practices of other agencies were across the country to prioritize the installation of guardrail.

The project statement was to define a methodology to evaluate the safety improvements of selected locations of the county road network considering all relevant factors such as traffic, roadway and roadside geometry, type of facility, crash history, etc. and to allow for the comparison of alternative improvement layouts. Most importantly, the methodology was to provide a priority ranking of all the locations to determine which ones should be improved.

The original idea as to how to approach this project was conceived by the Research Team as having two phases. Phase I would concentrate on the analysis, evaluation and prioritization of a list of candidate sites provided by the County. Figure 1.1 presents a diagram of the main steps undertaken in that phase.

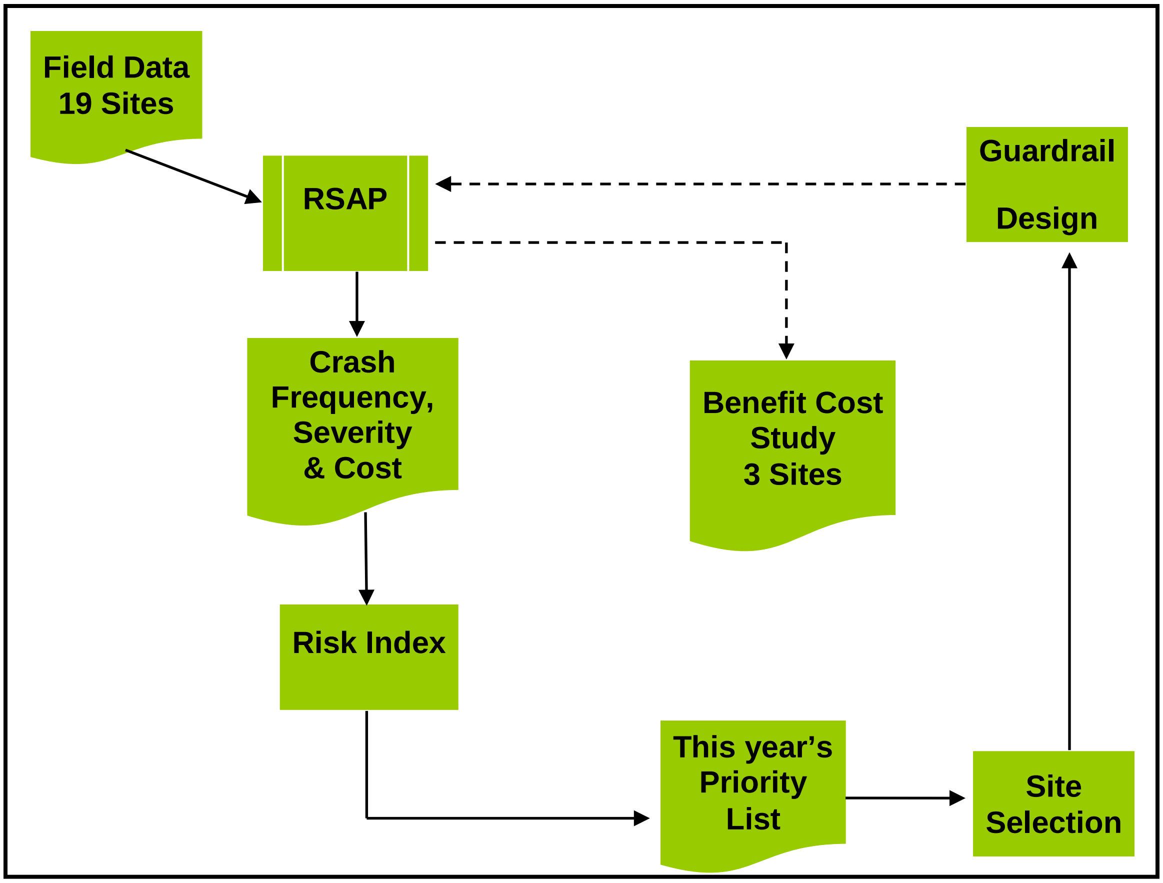

Figure 1.1: Methodology for Hillsborough County's project. (*2*)

Phase II would look beyond the immediate list of sites and develop a methodology that would help to develop such a list based on the assessment of risk of occurrence and severity of run-off-road accidents on the entire county road network. That methodology is presented in Chapter 3. The scope of work contracted by the County was for the first phase and the results were presented in January 2005 (*2*). This dissertation builds upon those results and presents the work that has been done to develop a methodology that would aid in phase II.

1.3 Historical Crash Database Analysis and RSAP

It is not uncommon to use crash database analysis to identify locations that should be further analyzed for road safety improvement projects. As with any other methodologies, crash database analysis has its own limitations.

The problem of under-reporting of traffic accidents is well known: not all the accidents that occur in a given year make it to the corresponding databases. This is especially true for single vehicle accidents (like run-off-road accidents) when the driver is able to drive away from the scene before a police officer is called by neighbors. Moreover, there are also many run-off-road events that cause only minor damage to the vehicle (like a damaged tire that will go unnoticed—even for many months—by the vehicle's owner) and which the driver itself would not even call it an accident.

Then there is the "return to the mean" problem. In this case, the occurrence of many crashes at a given site over a period of time is followed by less than average number of accidents for another period of time so that the long term trend remains within normal limits. Somewhat related to this issue is the most fundamental one that the crash database approach is somewhat reactive. Studies and projects will be conducted where the accidents have already occurred. As a matter of fact, from a probabilistic perspective, the user of historical crash data should be careful of this "return to the mean" condition: a reduction in crash rates at a site after the implementation of a safety project might not be due to the project. The observed result could have occurred due to the normal reduction that would have taken place (in a random process) even without the implementation of the safety project.

In the original project for Hillsborough County, RSAP was used to evaluate each site (*2*). RSAP is an acronym for "Roadside Safety Analysis Program". RSAP analysis is based on a probabilistic approach for estimating the number of potential run-off-road accidents for a given study section each year, based on the existing conditions of traffic, road geometric and roadside environment. RSAP uses a series of probabilistic distributions for several of the key variables in conjunction with a Monte Carlo simulation procedure combining all these factors to determine the likelihood of having an accident and its consequences in terms of severity and associated costs (*3*).

The strengths and weaknesses of RSAP and of the methodology applied to the original project for Hillsborough County provided the foundation for the research presented in this dissertation.

RSAP does not explicitly consider the crash history of a site. From a theoretical point of view this is correct. A high crash rate in a given year for a specific location does not necessarily suggest that the condition will repeat in subsequent years, unless a non-random cause exists.

Historical data might, however, be useful precisely to uncover non-random conditions that prevail at a given site. RSAP gives the option of specifying an "Encroachment Rate Adjustment Factor" to reflect knowledge of such prevailing local conditions. This factor has a default value of 1.0 and it multiplies the expected frequency of yearly encroachment for the applicable site. A factor of 1.5 implies that the calculated value for the site would be increased by 50% therefore creating a higher chance of having more crashes depending on the conditions of the roadside environment.

It was known that most of the study sites analyzed in this project have had a history of crashes, and in some of them even some fatalities have been reported. However, there was not any rationale that could support the development of site specific factors that could be used in the RSAP analysis.

1.4 Research Objective

A preliminary literature review was conducted to use the most current information and data available under the consideration of appropriateness of purpose given the nature of the road network under study. Available methodologies for evaluating roadside improvement projects were evaluated. Moreover, in the original project for Hillsborough County a survey of current practices was conducted among other transportation agencies to learn how they were dealing with similar issues.

With this information and knowledge, the research objective was to develop statistically significant regression models to obtain estimates of the annual run-off-road crash costs of road segments on a rural network. These estimates would be used to perform a fast evaluation at the network level, that is, of all links in the network. The models would be constructed based on the RSAP analysis and output, and on the data required and collected to conduct such analysis. The results of this quick evaluation would be used to prioritize further evaluation of roadside safety improvement projects.

1.5 Overview of the Dissertation

This dissertation is divided into six chapters. This first chapter is the introduction. The second chapter presents a literature review and it includes a survey of current practice conducted at the time of the original project for Hillsborough County to determine what procedures were being used by other agencies around the country. Chapter 3 is a detailed explanation of the procedures implemented for the execution of this research project. Chapter 4 presents the data collection process accomplished in the field and supplemented by available information in the office. Chapter 5 presents the analysis conducted with the available data and the results obtained while Chapter 6 summarizes the dissertations contributions to current knowledge and presents the conclusions and recommendations for future research.

1.6 References

1. AASHTO. *Highway Safety Manual*. American Association of State Highway and Transportation Officials, Washington D.C., 2010.

2. Delgado, I., J. J. Lu, and J. C. Pernía. *Methodology to Assess the Risk of Run-Off-Road Accidents in Hillsborough County Road Network*. University of South Florida, Department of Civil and Environmental Engineering, Transportation Program. Report presented to the Engineering Division, Public Works Department, Hillsborough County. Florida. 2005.

3. Mak, King K. and Sicking, Dean L. *NCHRP Report 492: Roadside Safety Analysis Program (RSAP)—Engineer’s Manual*. Transportation Research Board of the National Academies, Washington, D.C., 2003.

CHAPTER 2: LITERATURE REVIEW

This chapter begins by introducing the evolution over the past decade of the RSAP software. It then proceeds with an overview of historical crash data in the United States. It follows with a summary of several existing methodologies and approaches that are in use or have been proposed across the nation to prioritize roadside safety improvement projects.

2.1 The New RSAP2012 Software

This dissertation is based on the results obtained with the RSAP software released in 2003. The author was expecting a new version of the software to be available by the end of 2010 to conduct the final analysis for this research. However, it now seems that the new version will not be released to the public probably until 2012. This section gives a brief summary of the evolution of the RSAP program leading to what will be referred to as RSAP2012 in this dissertation. It is recommended in Chapter 6 that the analysis and results that have been used and obtained in this research should be repeated with the RSAP2012 once it becomes available to the public.

The Roadside Safety Analysis Program (RSAP) was the result of the research effort undertaken in the NCHRP Projects 22-9 and 22-9(A). The software was distributed as part of AASHTO's 2002 Roadside Design Guide (*1*). It was later available for download from the TRB website (*2*). Before the end of the last decade, it was notorious that the program had some bugs and problems that could not be fixed under the original contracts. Moreover, although the program's had a solid foundation built around the encroachment probability approach, some of the default relationships and data tables were being questioned at the same time that more recent research had become available.

Under these circumstances, a new research project (NCHRP 22-27) was awarded to Dr. Malcolm H. Ray of Road Safe LLC to update and re-code the RSAP program (*3*). The original contract end date was July 27th, 2011 (*4*). The research effort is currently on Phase II and the project NCHRP 22-27 is considered active with an announced completion date of June 30th, 2012. A preliminary draft final report is expected for March of that year (*5*).

The new software that will result from this new project is being called RSAP2012 in this document. There are several new developments that are expected to be incorporated into the new program. The author learned about two that have been made public:

- New encroachment modeling
- New approach for estimating crash severity (*6*)

The second one seems to be an on-going effort that will be incorporated into future updates of RSAP (*7*). It involves the use of the Probability of Injury (POI) method and the development of look-up tables using existing crash databases already maintained by the States.

2.2 Crash Data and Rural Roads

Traffic fatalities final numbers are usually published with a lag of a couple of years. Early estimates for the year 2010 indicate (*8*) that 32,788 people died in motor vehicle traffic crashes. The figure for 2009 was 33,808. Although these are very high numbers, they are significantly lower than what the historical values have been as seen in Table 2.1.

Table 2.1: Traffic fatalities in the United States 1993-2010

Year	Total Traffic Fatalities	Rural Area	Urban Area	Undefined
1993	40,150	n.d.	n.d.	n.d.
1994	40,716	n.d.	n.d.	n.d.
1995	41,817	n.d.	n.d.	n.d.
1996	42,065	n.d.	n.d.	n.d.
1997	42,013	n.d.	n.d.	n.d.
1998	41,501	n.d.	n.d.	n.d.
1999	41,717	n.d.	n.d.	n.d.
2000	41,945	24,838	16,113	994
2001	42,196	25,150	16,988	58
2002	43,005	25,896	17,013	96
2003	42,884	24,957	17,783	144
2004	42,836	25,179	17,581	76
2005	43,510	24,587	18,627	296
2006	42,708	23,646	18,791	271
2007	41,259	23,254	17,908	97
2008	37,423	20,987	16,218	218
2009	33,808	19,259	14,341	208
2010	32,788	n.d.	n.d.	n.d.

The above table also indicates the number of fatalities that occurred in roads located in rural and urban areas for the first ten years of this new century. It shows that the number of traffic fatalities have been consistently higher in the rural areas. However, when exposure is taken into account, the picture is even more dramatic. Only 23% of the population of the United States lives in rural areas (*9*). Table 2.2 presents the national annual fatality rate per 100 million vehicles miles traveled for the period 2000-2009. Rural and Urban rates are also presented.

Table 2.2: Traffic fatality rates in the United States 2000-2009 (per hundred million vehicle miles traveled) (*9*)

Year	National Average	Rural Area	Urban Area
2000	1.53	2.29	0.97
2001	1.51	2.27	1.01
2002	1.51	2.30	0.98
2003	1.48	2.30	0.98
2004	1.44	2.36	0.93
2005	1.46	2.38	0.95
2006	1.42	2.28	0.95
2007	1.36	2.25	0.90
2008	1.26	2.12	0.82
2009	1.14	1.96	0.73
2010	n.d.	n.d.	n.d.

Many of these fatalities occurred in run-off-road type of accidents. Out of the 289,979 traffic fatalities that occurred between 1993 and 1999, 28.2% (81,784) were run-off-road crashes. Typically this involves a single vehicle that unwillingly leaves the roadway and unable to recover will hit some element of the roadside environment, i.e. a tree, a guardrail, an utility pole, an embankment, etc. See Table 2.3 for a breakdown.

Table 2.3: Number of fatalities by feature type in the United States 1993-1999

	1993	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Run-Off-Road Total	11,292	11,237	12,015	11,906	11,695	11,731	11,908
Tree	3,035	3,014	3,198	3,128	3,220	3,226	3,348
Culvert/Ditch	1,359	1,380	1,476	1,437	1,396	1,491	1,481
Embankment	1,060	1,143	1,269	1,239	1,186	1,206	1,268
Guardrail	1,128	1,125	1,191	1,137	1,159	1,248	1,185
Utility Pole	1,274	1,096	1,135	1,096	1,111	1,092	1,070
Curb/Wall	810	830	921	947	915	823	753
Sign/Light Support	471	453	580	634	514	504	546
Bridge/Overpass	448	434	459	435	431	402	409
Other 7 Features	1,707	1,762	1,786	1,853	1,763	1,739	1,848

Since 1979, the proportion of traffic fatalities involving the collision with a fixed object on the roadside environment has fluctuated between 19 and 23% (*10*). In some cases there might be a roll-over of the vehicle.

It is interesting to notice that in Table 6.2 the participation of trees is 27.1% in average while that of utility poles is 9.6% in average. The corresponding data for the year 2008 (*10*) is 48% and 12%. Similarly, the participations of guardrail and embankment are 10.0% and 10.2% in average while the data for 2008 is 8% (feature's name in that reference is traffic barrier) and 6%. Culverts and ditches participation was reduced from 12.3% to 6%.

2.3 Various Approaches to Assess the Impact of Run-Off-Road Accidents

In the previous section we have reviewed data on traffic fatalities with an emphasis on rural roads and run-off-road accidents. It is important to notice that there has been a significant reduction in the number of fatalities and on the fatality rates. Many factors contribute to this success. However, there are about 20 daily fatalities caused by the hazards present in the roadside environment. The urgency to understand the problem and to search for solutions is more pressing when injuries and property damage is brought to the equation.

2.3.1 Historical Crash Data Based Approach

Crash data based procedures make use of statistical models based on the analysis of crash data from police report records to predict crash frequencies and severities. In general these statistical regression models are developed:

- Site specific, using crash data collected at one site
- Feature specific, using data from several sites (cross section data).

Site specific analysis is the best approach if significant crash data is available, which is often not the case. Feature specific analysis requires the use of large databases of crashes involving the feature under consideration. Separate models are developed for different types of features and this greatly complicates the type of analysis required in a cost benefit study having the goal of evaluating a comprehensive roadside safety improvement project.

Both approaches are susceptible to the quality of data found in police reports, and most importantly, to the lack of data most of these databases have. Many of the low severity type of accidents will go unreported and will not show in the databases. Moreover, some features have higher rates of reported crashes than others (utility poles as compared to break away sign supports for example). Moreover, other "problems associated with police-level crash data include inaccurate and improper coding by the reporting officers, incorrect use of nomenclature, lack of detail on the reported variables, and inaccurate location coding of crashes". (*11*)

Another problem with the use of regression analysis in particular for run-off-road type of accidents, is that they are affected by numerous factors not necessarily related to the roadway, the roadside, or the traffic conditions; and which are commonly left out of the regression models. Two of these factors could be driver demographics and location of drinking establishments.

At a specific site, the common practice is to use available data to forecast the expected future crash frequency and to apply an accident reduction factor (typically developed separately from a series of “before-and-after” studies of specific road improvement projects) to compute the savings associated with a proposed project.

It is important that these “before-and-after” studies be developed cautiously in order to avoid falling into the “regression-to-the-mean” trap. Control sites need to be established to determine what proportion of the crash reduction is truly associated with the safety improvement. The random variation of crashes might result in a “higher than normal” crash rate during the period of the “before” study which could have been followed by a lower crash rate in the “after period” of the study even if nothing was done to the site.

2.3.2 Probabilistic Approach

This approach has been studied as an alternative to the disadvantages presented in the previous section for the crash data based methods. The crash frequency in this probabilistic approach is assumed to be proportional to the encroachment frequency and this in turn is developed as a function of road type and traffic volume.

Encroachments are assumed to occur randomly and uniformly along any length of straight and level roadway. Factors are then used to adjust for parameters that affect this basic encroachment rate such as vertical grade and horizontal curvature. Basic assumptions about the kinematics of an encroaching vehicle lead to the construction of the “hazard envelope” for each roadside feature. This “hazard envelope” is a function of the geometry of the hazard (size, location and offset), the size and orientation of the vehicle, and the encroachment angle.

For a given encroachment in a road segment under study, the probability of impacting an existing hazard is then the conditional probability of having an encroachment with a given set of values for the variables that influence this probability (vehicle size, traveling speed, vehicle orientation, encroachment angle) times the conditional probability that the encroachment will be within the “hazard envelope” and then adding the product over all possible values of the conditional variables.

Given that the encroachment resulted in a crash, the next step is to determine the probability of having a crash of a specific severity level, while the final step would be to determine the cost of each estimated crash.

This probabilistic approach has been evolving since the late sixties and it has been implemented in several studies. A graphical solution technique was part of the 1977 AASHTO Yellow Book (*12*). A simulation program to study the behavior of vehicle upon leaving the roadway was developed at the University of Nebraska in the late seventies. In the mid-eighties, the Texas Transportation Institute (TTI) developed the ABC program that was later modified by the FHWA to create BCAP (Benefit Cost Analysis Program) somewhat implemented in AASHTO’s Guide Specifications for Bridge Railings of 1989. (*11*)

Finally, a simplified version of BCAP was developed by FHWA and became the ROADSIDE program that was presented as part of the 1996 edition of the AASHTO Roadside Design Guide (*13*). This software had some limitations that required the users to make several runs to fully analyze a site. The users then had to manually combine the intermediate results to obtain a satisfactory final answer.

In 2003, NCHRP Report 492 (*11*) presented RSAP as the culmination and final report of the NCHRP Project 22-9(2). RSAP stands for "Roadside Safety Analysis Program" and it uses the encroachment probability approach.

2.3.3 Combined Approach

The corner stone of the encroachment probabilistic approach presented in the previous section is the encroachment data. Two sets of data have been collected in the past. One is known as the Hutchinson and Kennedy data and it was collected in the mid-sixties. The other one is the Cooper data. It was collected in Canada in the late seventies. Both of them have some deficiencies and some efforts have been directed towards obtaining better data sets. However, these field efforts have not yet yielded better results.

Texas Transportation Institute conducted a research project for the FHWA aimed at estimating the roadside encroachment rate using an approach combining the strengths of the two methods presented in the previous sections. Their conclusion is that "the proposed method could be a viable approach to estimating roadside encroachment rates without actually collecting the encroachment data in the field, which can be expensive and technically difficult" (*14*).

2.3.4 Use of GIS for a Systematic Approach

A paper by Brewer, Ellison, and Grindley (*15*) presented a concept based on the use of Geographic Information Systems (GIS). The paper describes "how locations where roadside safety improvements may be needed can be identified". The paper indicates that GIS could serve as an effective tool to identify these locations on a "system wide" by integrating collision data into GIS. This effort would be like collecting crash data for a given region under the historical crash based approach.

This step would identify “black spots”. The next step would be to consider key roadway characteristics that can have a potentially significant influence in run-off-the-road type of crashes:

- crash history on roadway segment (frequency, severity, type, length)
- embankment conditions
- horizontal curve and downhill grade
- lane and shoulder width
- roadside obstacles
- traffic volume
- speed limits

These individual factors would receive a weight based on the agency’s own policies. For each site, each factor would also receive a score and a final weighted score would be obtained for each location. These scores would be a way of comparing sites basically providing a ranking scheme to aid in the selection of which sites to do with the available funds. Other criteria could be used to do the final selection.

No other reference was found as to any further implementation.

2.3.5 University of Virginia Risk-based Management Approach

In 2001, the University of Virginia presented its final report (*16*) to Virginia DOT entitled “Risk-Based Management of Guardrails: Site Selection and Upgrade” in which it addresses “the need for allocation of resources to run-off-the-road and fixed object hazards” in Virginia’s secondary road system of some “60,000 miles of roadway with yet uncharacterized hazards in need of guardrail upgrade, installation, or related warning signs or protection”.

The project developed an information system accounting for the potential crash severities, traffic exposures, costs of treatment, and other factors with the explicit premise that no one selection criteria would be applicable across all localities, including also cost benefit ratio criteria. The information system developed had three components:

- database for archiving and comparison of protected and unprotected hazards
- screening of hazardous corridors within a region
- site evaluation based on multi-criteria cost benefit analyses of guardrail locations

No further information was found as to further applications of the results from this research.

2.4 Information Survey

Delgado, Lu and Pernía (*17*) conducted a mail-in survey in 2004 to review the procedures used by different States to prioritize the selection of sites for guardrail installation. The survey was sent to the Department of Transportation (DOT) at each of the 50 states plus the District of Columbia and Puerto Rico. Twenty five agencies responded this survey, and some of them elaborate in their current procedures as discussed below. Figure 2.1 identifies the States from where responses were received.

Figure 2.1: State highway agencies (DOT) responding the survey

Prioritizing guardrail installation was not a concern for only one of the agencies that responded the survey. For that agency, the criteria was to install guardrail (or other protective measurement) “wherever needed” according to existing site conditions. On the other hand, sixteen agencies (almost 65% of those responding) said that they do not have a specific procedure to prioritize the installation of guardrails. However, many of them mention that in general installation of guardrail and improvements to existing hardware are considered as a component of other major roadway investments.

For improvements, three of the responders specifically mentioned the NCHRP 350 requirements. In this same group of respondents, some “key” factors were frequently mentioned as part of their decision making process with regard to guardrail:

- hierarchy of the network (state roads had higher priority than others)
- accident history at given locations
- traffic volume
- conforming a more attractive bidding package

Another third of the respondents acknowledge the use of a specific procedure to prioritize the installation of guardrail. Most of them have the following as common variables:

- traffic volume
- accident history
- cost benefit results
- noncompliance with current standards

It is fair to mention that in analyzing the responses of the survey, there seems to be an overlap between these two groups. Some of the agencies in this second group relate their procedure to their own roadway design manual as an aid to determine if a “pre-selected” location warrants guardrail or not. Other responders made direct references to AASHTO’s “Roadside Design Guide” and FHWA’s “Design, Construction and Maintenance of Highway Safety Features and Appurtenances”. NCHRP Report 350 was also mentioned.

None of the agencies seem to have a procedure to obtain a list of all possible candidate sites potentially in need of guardrail hardware along with a prioritizing methodology to determine which ones should be done first for a given objective.

It might be argued that all of the agencies consulted in this survey deal with state roads and highways and that most of their location in need of guardrail already have some installed hardware; and that consequently, their concern is more with bringing this existing hardware up with current safety criteria (like that of NCHRP Report 350) and design specifications. Many of them also expressed greater concern for guardrail needs in highway medians.

2.4.1 Washington State

Washington State DOT addresses the need of guardrail as an integral part of their preservation projects and improvement projects following a design procedure established in their own Design Manual. In the case of preservation projects their focus is on maintaining "the existing infrastructure, and to make low cost safety improvements" such as adjusting guardrail height as needed, improving terminals and transitions and adjusting the length of existing hardware.

In the improvement projects, the emphasis would be to "utilize guardrail as necessary for shielding hazards". In these cases, current standards are always used. They also have some specific funds targeting "Special Safety Initiatives" with which they improve "older style guardrail designs" with a "find it and fix it" approach. However, none of the procedures in any of their three programs addresses "how to prioritize independent guardrail runs on a system-wide" basis.

They do have a list for installation of median barrier, and work on a prioritization scheme based on benefit cost analysis, comparing “the installation and maintenance costs against the societal cost associated with reductions in accident severity”. Part of the reason for having this list is because they currently have a “Stewardship Agreement with the Federal Highway Administration… to proactively address safety issues independently from preservation work”. They have specific funds earmarked by the state legislature to address median cross-over collisions.

2.4.2 Texas

Texas DOT “does not prioritize the installation of guardrail”. They “install guardrail, or other barriers, wherever needed due to slope conditions or fixed objects within the horizontal clearance areas”.

2.4.3 New Jersey

New Jersey DOT installs guiderails (their terminology for guardrails) along roadsides in conjunction with initial highway construction in accordance with their highway design standards. When highways are upgraded, guiderails are brought up to current standards.

They receive requests from citizens and elected officials to install additional guiderail. They evaluate these requests and if guiderail is warranted, it is installed. These requests are not prioritized. They also acknowledge their concern with increasing cross median crashes.

2.5 Summary of Findings

The state-of-the-practice survey conducted reveals that although run-off-road accidents is a substantial burden on the transportation agencies across the country, there has not been a systematic approach for evaluating attenuation alternatives on a system wide level within each state. Moreover, those states that have a specific procedure to prioritize the installation of guardrail do not seem to have (maybe because they do not feel the need of having) a screening and ranking procedure that could ensure the most beneficial used of the limited funds available.

Most of the research conducted in the last decade has been aimed at improving the ability of the analyst to conduct a cost benefit analysis for the conditions at a given site. Many improvements have been made in the software available with regards to user interface. Not much attention is reported with regard to assessing the risk of run-off-the-road type of accidents on the entire road network of a given agency.

2.6 Conclusion

For the objective of this research, as presented in Chapter 1, which is to develop statistically significant regression models that could be used to perform fast evaluations of all links in a road network to prioritize roadside safety improvement projects, it seems that the models can be constructed based on the RSAP analysis and output, and on the data required and collected to conduct such analysis.

Not only RSAP has a solid analytical foundation but it also has attracted extensive research that will make it even a much better support model for our objective.

2.7 References

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CHAPTER 3: METHODOLOGY

As presented in the previous chapter, the review of existing procedures for evaluating roadside safety improvement alternatives led to the adoption of the Roadside Safety Analysis Program (RSAP). RSAP was distributed as part of the AASHTO Roadside Design Guide 2002 (*1*) and it has been available to the public for downloading through Transportation Research Board (TRB) website (*2*).

The results obtained in this dissertation are those of version 2.0.3 of the RSAP model (dated April 28th, 2003) as available on March 17th, 2011. A newer version of the model (“RSAP2012”) is currently on the works and scheduled to be delivered in 2012 but no product is yet available to the public.

This chapter presents a detailed description of the methodology used in this research project starting with a description of the probabilistic approach implemented into the RSAP software package. It then proceeds to present the proposed modeling forms that will be pursued in the next chapters.

3.1 Probabilistic Approach Implemented into RSAP

Equation 3.1 is the basic equation that describes the probabilistic approach:

$$\boxed{\text{Expected Crash Cost} = [\text{ADT} * p(E)] * [p(\text{Crash}/E)] * [p(I/\text{Crash}) * \text{Cost}(I)]} \tag{3.1}$$

Equation 3.1 indicates that the estimated or expected value of a crash depends on the probability of having an encroachment (E) times the traffic volume (ADT), multiply by the probability of having a crash given that an encroachment has occurred, multiply by the probability of a given injury level (I) given that there has been a crash times the cost of the injury level. Each bracket identifies a module within RSAP (*3*).

First there is the encroachment module. The annual encroachment frequency is computed based on roadway characteristics and traffic volume. The fundamental data comes from a study from the late 70's referred to as the Cooper's data. For a straight and flat section of road, this data provides an estimate of the expected number of encroachments per unit of length at a given traffic volume. This raw number is then adjusted by the length of the section, its grade and curvature. Finally, the result is multiplied by the volume of traffic to compute the number of encroachments for the year.

The second module is the crash prediction. Not all encroachments will result in a crash. Given the existence of a roadside safety hazard, the occurrence of a crash given an encroachment would depend on:

- Encroachment location
- Encroachment speed and angle
- Encroachment extent
- Vehicle type
- Vehicle trajectory off the road
- Driver's reaction and actions

The last set of variables is not explicitly addressed in the current version of RSAP. The vehicle's trajectory (or swath path) off the road is assumed to be straight without any braking. All the other variables are modeled using probabilistic distributions based on real world crash data.

Monte Carlo simulation techniques are applied to each encroachment, one at a time. For a given study site having several segments, applicable probabilistic distributions are used to determine the point of encroachment based upon:

- Segment in which the encroachment occurs,
- Location within the segment,
- Direction of travel,
- Lane in which the encroachment originates, and
- Direction of the encroachment (right or left)

Similarly, probabilistic distributions (appropriate for the roadway type and its posted speed) are used to determine the encroachment speed and angle. For any given roadside feature input by the analyst, RSAP knows its location coordinates and it then determines if the encroaching vehicle's path will lead to an impact with that feature.

Finally, there is the severity prediction module. If an impact is predicted, the severity of the impact is assessed using built-in equations that take into account the type of roadside feature and the speed of the vehicle at impact. The computed severity index is mapped with the estimated percentages of different injury levels built into the RSAP model. These proportions are multiplied by the corresponding crash costs selected by the analyst. The crash cost values used for the evaluations in this research are those referred to as AASHTO Roadside Design Guide (*3*). The program will also consider the possibility of an errant vehicle striking more than one roadside feature by computing the remaining kinematic energy remaining after each impact. The strike having the highest severity index is the one that will be used for crash cost estimates.

A final adjustment is made to this crash cost estimates to take into account the probability that the vehicle will be stopped or steered back toward the roadway before running into any roadside feature.

This process is repeated for each predicted encroachment, and for each roadside feature. RSAP then reports the calculated Annual Crash Cost for the feature. This calculated value now becomes the target variable that this research aims to predict.

Finally, for each study segment in this research, RSAP computes the annual crash cost of all the roadside features in the segment. This value can be used to compare the relative safety condition of the roadside environment among various segments.

3.2 Alternative Methodology to Model Roadside Safety Hazards

RSAP in its current version has been around for well over a decade. The program has been successfully used to perform cost benefit analysis of roadside safety improvement projects. And although RSAP was also used to provide a ranking of 19 sites of the Hillsborough County road network (*4*), the program is not suitable to obtain a network level assessment of roadside safety.

The question was then how to use the strong theoretical foundation and analytical capabilities of RSAP to develop a tool to improve the level of safety of the roadside environment of a large road network of heterogeneous conditions and levels of traffic given the ever present restriction of limited resources and funding.

The experience with RSAP clearly indicates that crash costs associated with different roadside safety environments were a function of the nature of the hazards and their location with respect to the traveled lanes. If this information were readily available, then it would be possible to study their relation with what RSAP would predict.

There are many methods to obtain this data: the basic one is through manual field measurement. In this case, the production rate will depend heavily on the technological level of the measuring equipment being used although the quality of the data would be quite the same for most practical applications. On the other extreme, technological advancements nowadays provide automated data capturing and processing of images with very high output rates and within the desired quality. Then in between, there are visual methods that can provide estimated values of sufficient quality and accuracy to yield acceptable results. One final possibility is to use these approximate methods to obtain simpler categorical values.

In this research we had obtained very high quality data with manual field measurement techniques using basic instruments. Consequently, it was deemed worthwhile investigating if the data obtained could be used to develop models to estimate the values calculated by RSAP.

3.3 Data Requirements and Modeling

This research built upon the work and results of a previous project executed for the Hillsborough County Engineering Division (*4*). The initial list provided by the County had 19 sites of diverse characteristics that were selected based on their knowledge of needs, taking into consideration crash history and public requests. Those 19 sites were evaluated using RSAP to provide a ranking of which sites had the most urgency for roadside safety improvements projects. Figure 3.1 presents the final ranking as presented in the original project to Hillsborough County (*4*).

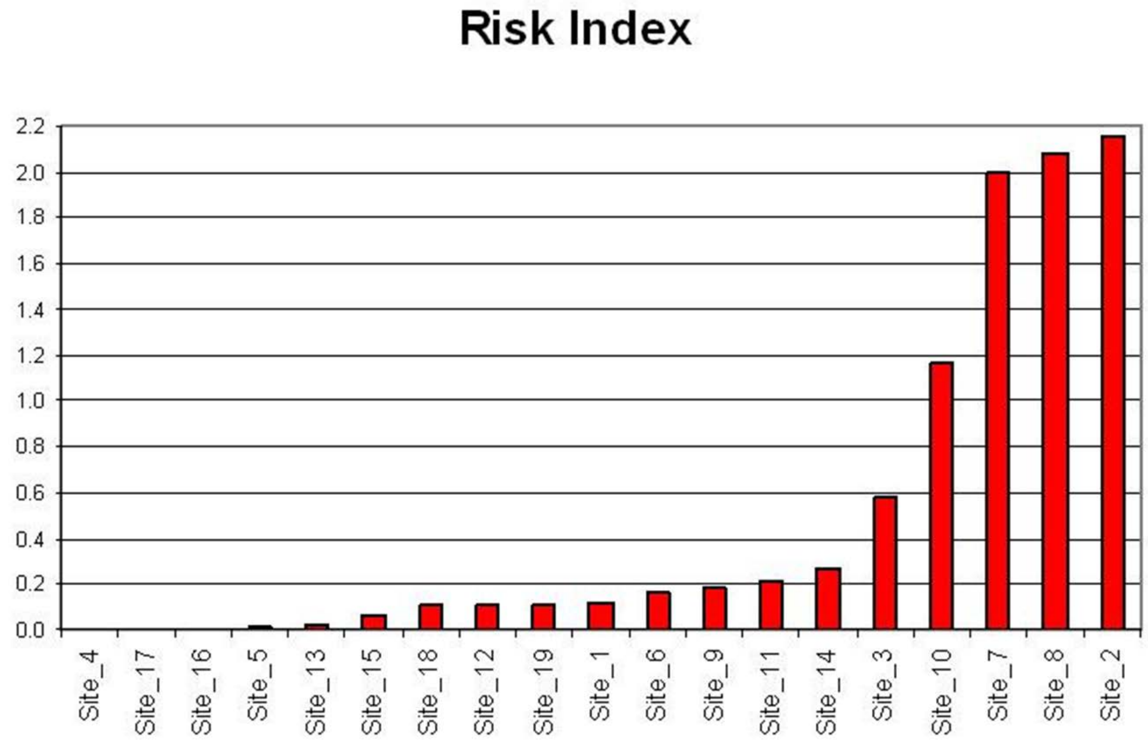

Figure 3.1: Risk index for 19 sites in Hillsborough County project. (*4*)

The data inputs required by RSAP as the modeling tool were studied to define the scope of the field data collection effort which is described in Chapter 4. These sites provided a total of 45 study segments and 337 roadside features that were analyzed using RSAP to obtain the expected values for total annual crash cost at each segment and for total annual crash cost for each feature. Table 3.1 presents the list of sites that were analyzed.

Table 3.1: List of 19 sites of the original project for Hillsborough County

Site	Main Road	Location	Reference
1	Riverview Drive		
2	Lake Magdalene Blvd.	West of Avila Boulevard	
3	Gunn Highway	West of Lutz-Lake Fern Road	
4	Newburger Road		
5	Newburger Road		
6	Gunn Highway	At Isbell Lane	
7	Hutchinson Road	North of Rawls Road	
8	Countryway Boulevard	At Snapdragon Road	
9	Hanna Road		Water drop off
10	Livingston Avenue	Near Bordeaux Way	
11	McIntosh Road	North of I-4	
12	McIntosh Road	North of I-4	
13	N. Dover Road	South of Martin Luther King	Box Culvert
14	N. Charlie Taylor Road	0.1 mi. North of US92	Box Culvert
15	Charlie Taylor Road	1.0 mi. North of Swindell Road	Box Culvert
16	Isabel Avenue		Along canal drop off South side
17	Mabrey Avenue	Intersection of Williams Street	Drop off canal West side
18	Nundy Avenue		
19	Balm Riverview Road		At horizontal curve

For a given feature type, equation 3.2 shows the basic approach: to develop linear regression models to estimate the total annual crash cost (y) as calculated by RSAP:

$$\boxed{y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon} \tag{3.2}$$

The explanatory variables (x_1, x_2, …, x_k) would be variables related to the location or dimension of the roadside feature under analysis. They could as well be values that characterize the segment, i.e. lane width, traffic volume, curvature, etc.

One limitation of this model that was foreseen from the beginning is that the value of the annual crash cost calculated by RSAP for a given roadside feature is influenced by variables that in real life belong to another feature. For example, the chances of a utility pole being struck by a car not only depends on its offset distance from the road, but it also depends on how steep is the foreslope that exist between the edge of the traveled way and the utility pole.

It was decided that this “across features” dependency would not be addressed and that its magnitude would be part of the random error term. It is also possible to imagine that there could be some interaction term among the explanatory variables for a given roadside feature that could be capture with a model such as the one represented by equation 3.3:

$$\boxed{E(y) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2} \tag{3.3}$$

The explanatory variables could be for example posted speed and offset distance. No such interaction terms were found to be statistically significant in the analysis presented in Chapter 5.

3.4 References

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CHAPTER 4: DATA COLLECTION[1]

The detailed field data collection effort was planned based on the available in-office information and the preliminary site visits performed to determine the prevailing conditions and the most appropriate approach in terms of efficiency and safety for the research team. This prior knowledge was very helpful for planning the logistics and making improvements as the field effort went underway.

4.1 Field Recognition of Selected Sites

Hillsborough County road network has more than 3000 lane miles, most of the roads having two lanes, one in each direction. All but one of the original 19 sites included were of this type. Some of the sites had very high levels of traffic that called for additional caution and safety measures to be considered for implementation during detailed field data collection.

As illustrated in Figure 4.1, there were some sites with visible indications of run-off-road events having occurred recently as indicated by skid marks, wheel tracks on the grass and some misaligned or hit and damaged road signs. As presented in Figure 4.2, the selected sites were spread all over the County and this factor had to be considered for the logistics of the data collection.

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[1] This chapter is based on the author's previous work (*1*).

Figure 4.1: Recent run-off-road event in Site 1

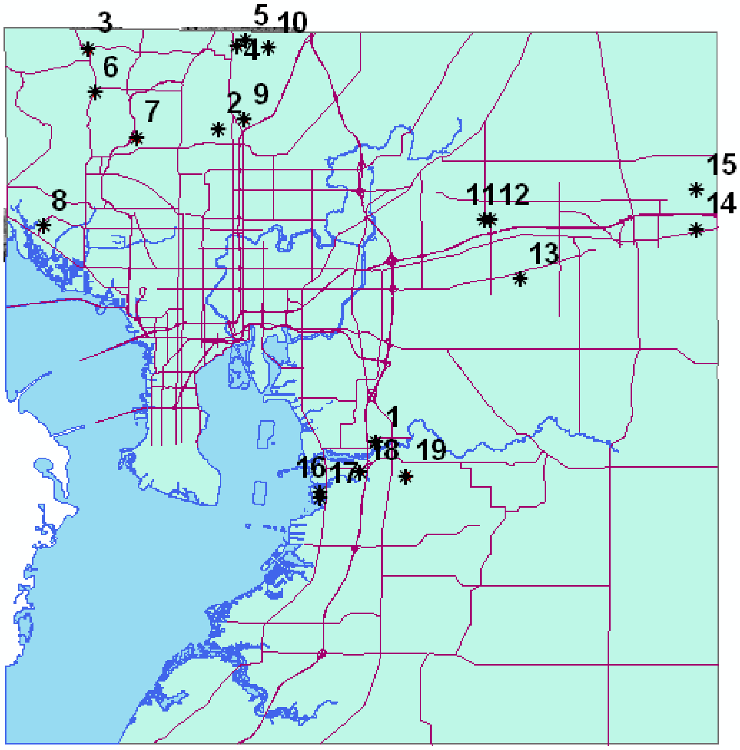

Figure 4.2: Location of study sites in Hillsborough County

All the sites would be classified as lying in rural areas although a few of them are located in fully built up residential areas. Most of the sites are located in minor collector roads and a few of them are in local roads. A very important result of this initial field recognition was the selection and definition of field reference markers that would be used to link each site to a common reference system as explained below.

4.2 Obtaining Basic Site Data

For each analysis location, RSAP requires four sets of data: Costs, Highway, Segments and Features. The second and third sets might be regarded as the general characteristics about the site being analyzed. Part of the basic data obtained during the preliminary stages of data collection provided some of the required data needed for the Highway set: Area Type (Rural, Urban), Functional Class (Freeway, Principal Arterial, Minor Arterial, Collector, Local), Highway Type (Two-way Divided, Two-way Undivided, One-way), and Number of Lanes.

Under the Segment data set, general data regarding each site were also collected. Basically an analysis site must be composed of homogeneous segments in terms of vertical grade, horizontal alignment and median type. For all practical purposes all sites were considered as having a complete flat grade, but a very important piece of information needed was the radius of curvature for those sites having horizontal curves.

The use of ArcGIS in conjunction with the aerial photographs proved to be a very powerful tool to acquire the required radii data without having to do additional field surveying. The reference markers defined during the initial field recognition were very useful at this point for the definition of homogeneous segments at each site location.

RSAP suggest that the speed data to be used for the analysis is the posted speed limit. The basic posted speed data was collected during the initial basic data collection.

4.3 Detailed Field Inventory

Once a full characterization of each site was obtained suitable for RSAP analysis, the most laborious part of the project started: the detailed field data collection. RSAP is a probabilistic simulation software package that predicts the chances of a vehicle running off the road. In such event, the program then proceeds to determine the vehicle trajectory and to evaluate what type of features exist along the vehicle path and what their characteristics are to simulate the impact, its severity, and its consequences. Therefore, one of the most important aspects for a realistic analysis is the description of what objects are to be found in the roadside environment for a given location.

There are a total of nine categories of features that define this roadside environment. These categories cover the terrain slopes on the sides of the traveled way; the drainage slopes and features; fixed objects such as sign posts, trees and light poles; longitudinal barriers such as guardrails; point barriers such as terminals and crash cushions; and user-defined miscellaneous features.

A very important parameter for the RSAP analysis is the traffic volume on each study site. Eleven of the 19 sites are included in an annual publication entitled “Roadway Level of Service Report” (*2*) prepared by the Planning and Growth Management group of the Transportation Division, Hillsborough County. In this analysis the data of the June 2004 edition was used. Traffic data for the remaining 8 sites were obtained from other available databases at the County, such as Hansen. These were reported as 2003 estimates.

4.4 Using Remote Sensing for Data Collection

Digital aerial photographs with a pixel ground resolution of half a foot (6 inches) were used to obtain a first approximation for lane and shoulder width. A pixel is the smallest non-divisible element in a digital picture. Any such picture will be shown at its neatest (sharpest) view when the monitor resolution is set to show one picture pixel in each screen pixel. However, it is possible to zoom in and out of this value.

For practical purposes, a ground element that is twice the size of the pixel ground resolution will be easily resolved from its surroundings and therefore clearly identified by the analyst. It is then possible to use the available aerial photos to see many of the most important features of each site and to measure (within an error of less than one foot) some geometric characteristics.

However, aerial photographs show a view from a vertical perspective and therefore some elements of the terrain, or part of them, might be hidden from view because larger elements would be closer to the “eye” of the analyst. Tree shadows represent a particular problem in this respect and although there are image enhancing techniques that would aid in solving these problems, they require specialized software and hardware that were not available for this project. For this reason, aerial photographs were used only as a first step in the data collection effort.

It is also possible to obtain terrain elevation data from aerial photographs using photogrammetric techniques, equipment, and software; but these alternatives were not pursued given the localized nature of the data in each site. Also, raster data in the form of digital elevation models (DEM) is also available for the study area. However, their best resolution is 1 by 1 meter and it was considered not high enough for some of the measurements that were needed in the field.

4.5 Geometric Characteristics

Geometry data for each site was first measured from available aerial photographs and confirmed through field measurements. Reference points selected from earlier visits were used in conjunction with the aerial photos to establish the length of each homogeneous segment at each site. All field measurements of length and distance were taken either by tape or by distance-wheel with a resolution of up to one inch. RSAP can handle either metric or US customary units. The latter were used during data collection for this research project.

4.5.1 Homogeneous Segments

Each of the 19 sites was divided into homogeneous segments. This resulted in a total of 45 study segments. Each analysis segment in RSAP must be homogeneous in terms of median type and width, vertical grade and horizontal curvature.

For the sites having a horizontal curve, three homogeneous segments were defined in each case: one for the curve itself and one for each tangent stretch before and after the curve, as shown in Figure 4.3. All horizontal curves were assumed to be circular. The location of the PC and PT of each curve was estimated to establish the length of each segment.

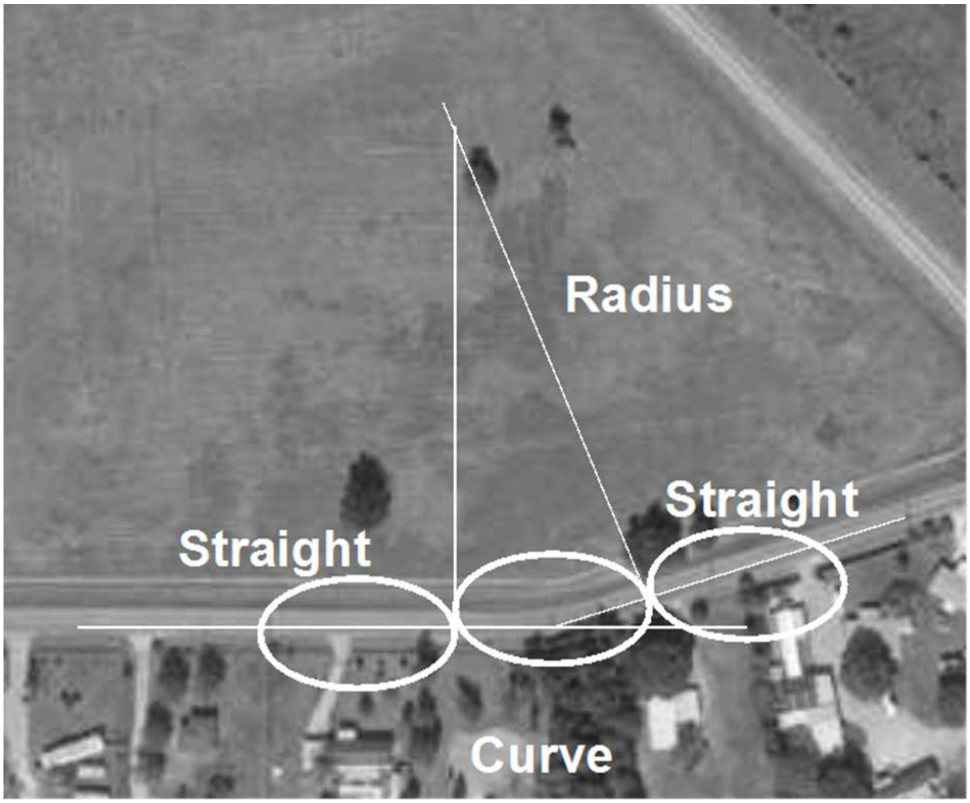

Figure 4.3: Segmentation of study sites having horizontal curves

The analyst must identify a point to mark the start of each study segment. This point is used as a reference to define the location of each roadside feature as discussed below. The length of each segment is also required.

4.5.2 Lane Width

For straight segments, the lane width was obtained by measuring the distance between the outer sides of the edge line for the through lanes and dividing it by two. In case of existing painted medians or left-turning lanes, the width of such areas was deducted from the total width. In case of existing right-turning lanes, the additional space was counted as part of the "clear zone" as explained below. In cases where the lane width measured was not constant for a given segment the narrowest width was used. This value leads to more conservative results.

On curved segments, the lane width measured was the outside lane. The measurement was taken from the middle point of the double center line to the outside of the edge line. This width typically varies along the curve: several measurements were taken and the smallest value was used as input for RSAP.

Only Site 8 had more than one lane in each direction and it also had a raised median. This site had a horizontal curve so the lane width measurement taken was in the outside lanes only and from the outer side of the inner edge lane (near the curb of the raised median) to the outer side of the edge line in the outside of the curve. This value was then divided by two. In this case there was one side road intersection in the curve so the "imaginary" projection of the edge line was used while measuring in that area. There was also a left turning lane towards the end of the horizontal curve but it had no influence on the lane width measurements.

4.5.3 Shoulder Width

According to the AASHTO (*3*), the shoulder element of the roadway is part of the "clear zone" concept that helps in reducing the risk of, or the severity associated with, any potential accidents which involve vehicles leaving the traveled way. In general, a shoulder might have an all-weather surfacing material such as "gravel, shell, crushed rock, mineral or chemical additives, bituminous surface treatments and various forms of asphalt or concrete pavement" to provide better "load support than that afforded by the native soils."

For practical purposes, if an area adjacent to the edge line was covered by grass or did not exhibit any obvious engineering characteristics, it was not considered shoulder but rather a side slope as defined below. Only two sites were considered as having “paved” shoulders as indicated in section 4.5.6 Data Summary. In general it could be said that as far as RSAP terminology, the term shoulder is limited to designated paved elements.

Shoulder width was measured from the outer side of the edge line to the edge of pavement (at observable full depth of the wearing course) provided that it was at least one foot wide. Measurements were taken on both sides of the traveled way for sites having no horizontal curves and only in the outer side of curved segments. In the first case, the reported value was that of the average value obtained from several measurements.

In the case of curved segments, the shoulder width sometimes tends to vary along the curve length. The minimum of all measurements was used as input into RSAP to produce consistent conservative results.

4.5.4 Median Type and Width

Median type in RSAP is a function of the highway type which can be classified as divided or undivided. In case of divided highway, the median is the stretch of land separating opposite directions of traffic. If the highway is undivided, then it might be that there is no median or that the median is only painted (meaning an area wider than the two parallel solid lines indicating a no passing zone) on the pavement. Another option might be that the two directions of through traffic are separated by a two-way left-turn lane applicable to undivided highways.

Where existent, the width of the median was measured and recorded. In case of painted medians, it was common to find that the width varied along the segment. A representative value was input into RSAP in these cases.

4.5.5 Radius of Curve and Length of Curve

For those sites having horizontal curves, it was necessary to determine the radius of curve and the curve length in each case. This was done through available aerial photographs and ArcGIS editing capabilities.

All horizontal curves were assumed to be circular meaning that the curve itself would be part of the circumference of a circle of unknown radius R fitted-in to joint two tangent lines having different azimuth values and consequently having a deflection angle equal to the difference in their azimuths. In highway engineering design, the radius R would be selected according to the desired design speed and other considerations of the design vehicle. As far as the field data collection, the interest was to determine this value from the actual road layout.

Using the painted road center line as the reference line, the incoming and outgoing tangents of the circle were drawn as an ArcGIS shape file using the aerial photograph as a canvas background. Then a trial and error routine was started to draw circle of different radii that would fit both tangents and the actual curve delineated in the background.

Once a satisfactory curve was found the beginning and ending points of the curve (PC and PT respectively) were marked to determine the curve radius as the perpendicular lines to the tangents at these two points. The average of the two values would then be rounded to a whole number for input into RSAP that also requires the direction of the curve.

Because the interest of this project was to analyze run-off-the-road accidents and because their likelihood is much higher on the outside of a horizontal curve, all the horizontal curves drawn were referenced as deflecting to the left. The actual curve length was measured along the curve just drawn using the measuring tool provided with ArcGIS. This sequence of steps is shown in Figure 4.4.

4.5.6 Data Summary

The geometric characteristics of each site, as described in the above steps, are summarized in Table 4.1. These were the values used for the analysis with RSAP as described in the next chapter.

The table also shows the legal speed for each study site as indicated by the regulatory posted speed. Most curves also have warning signs including advisory speed limits. These values are also given in Table 4.1.

4.6 Clear Zone Concept

In the 1970’s, with the publication of the second edition of the AASHTO Yellow Book (*4*), many agencies began to implement the “clear zone” concept that called for the provision of an unencumbered roadside recovery area as wide as practical for each specific highway section. Studies at that time indicated that a width of 30 feet or more from the edge of the trough traveled way would allow about 80 percent of the vehicles—leaving the roadway out of control—to recover.

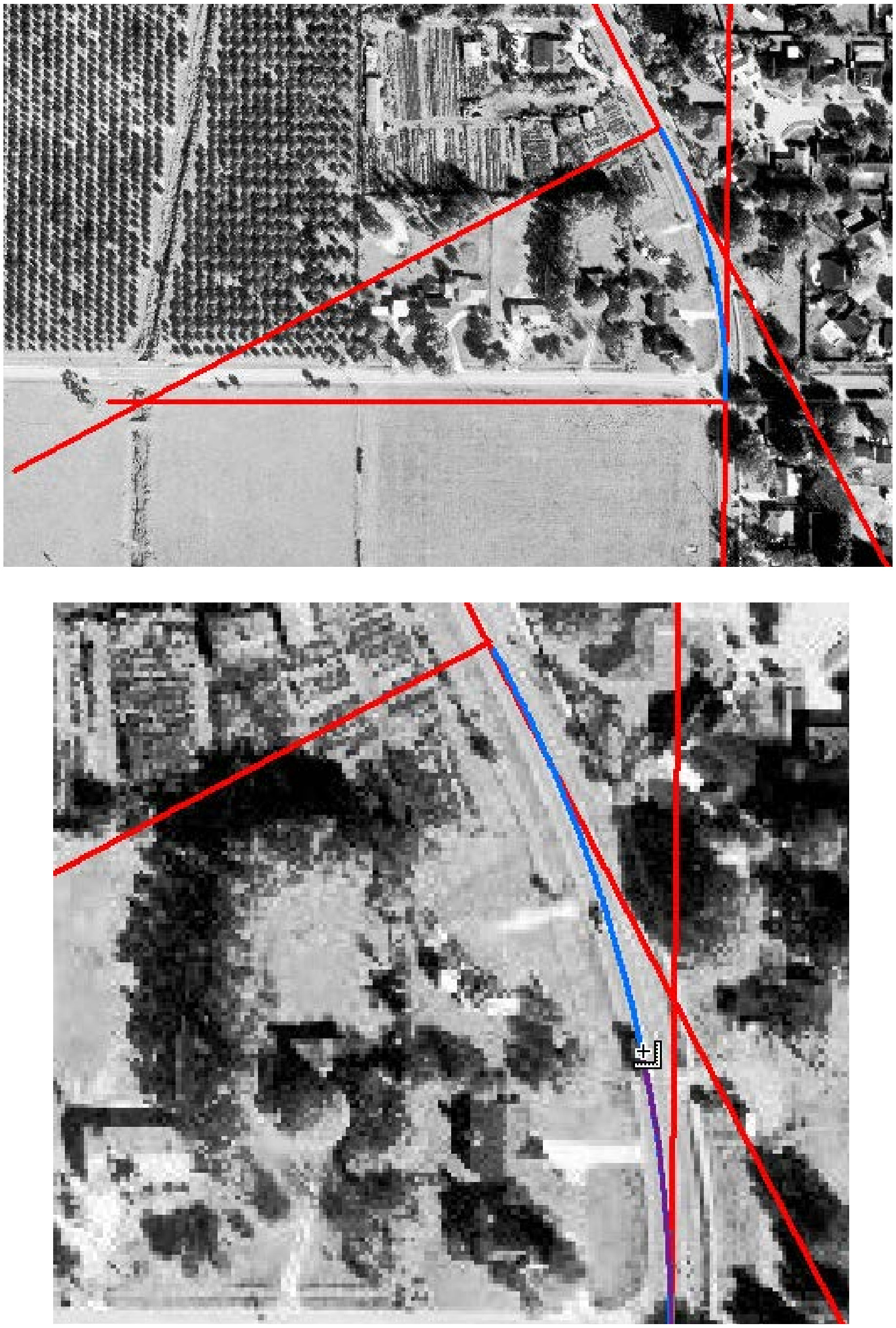

Figure 4.4: Estimating horizontal curve radius and length of curve.

Table 4.1: Summary of geometric characteristics and speed data for all study sites

Site	Location	Lane Width (feet)	Shoulder Width (feet)	Median Width (feet)	Radius of Curve (feet)	Length of Curve (feet)	Posted Speed (mph)	Advisory Speed (mph)
1	Riverview Drive	12.5	2.0	0.0	250	395	35	25
2	Lake Magdalene Boulevard	12.0	0.0	0.0	n.a.	n.a.	40	n.a.
3	Gunn Highway (at Lutz Lake Fern)	11.3	5.0	11.0	700	949	40	40
4	Newburger Road (Near US41)	10.5	0.0	0.0	50*	127	25	15
5	Newburger Road (by Cool Kell Lake)	10.5	0.0	0.0	150*	155	25	15
6	Gunn Highway (at Isbel Lane, near Van Dyke)	11.5	0.0	11.5	600	490	40	35
7	Hutchinson Road	11.0	0.0	11.0	1050	510	45	35
8	Countryway Boulevard	11.0	0.0	20.0	675	650	30	30
9	Hanna Road	10.0	0.0	0.0	150*	220	35	25
10	Livingston Avenue	10.5	0.0	0.0	n.a.	n.a.	45	n.a.
11	McIntosh Road (farthest from I-4)	10.5	0.0	0.0	200	315	40	25
12	McIntosh Road (nearest to I-4)	11.5	0.0	0.0	150*	235	40	25
13	N. Dover Road	10.5	0.0	0.0	n.a.	n.a.	45	n.a.
14	N. Charlie Taylor Road (near US 92)	9.5	0.0	0.0	n.a.	n.a.	45	n.a.
15	Charlie Taylor Road (north of I-4)	9.5	0.0	0.0	n.a.	n.a.	45	30
16	Isabel Avenue	8.0	0.0	0.0	n.a.	n.a.	25	n.a.
17	Mabrey Avenue	8.0	0.0	0.0	n.a.	n.a.	20	n.a.
18	Nundy Avenue	10.0	0.0	0.0	400	125	40	30
19	Balm Riverview Road	10.5	0.0	0.0	500	345	45	25

* Analysis was done with a value of 200 (minimum acceptable by RSAP)

However, it soon became apparent that in some situations even 30 feet would not be adequate while on most low-volume or low-speed facilities, thirty feet clear zone distance was excessive and could hardly be justified for engineering, environmental, or economic reasons.

By the end of that decade, AASHTO modified the previous clear zone concept and introduced the modified concept of “variable clear-zone distances” based on traffic volumes, speeds and roadside geometry. The 2002 Roadside Design Guide (*5*) presented this same modified concept. It also discusses the roadside features that a vehicle is likely to encounter upon leaving the roadway. The estimated values of the clear zone distance for each site is indicated in Table 4.2, as computed with that methodology.

RSAP uses the same type of roadside features in its analysis of accident severity for vehicles once they leave the traveled way (i.e., once an encroachment event occurs). This roadside feature data, needed as input for RSAP, was collected for the original project for Hillsborough County (*1*) and used more extensively for this research as discussed in the following sections and in the next chapter.

4.7 Roadside Features: Roadside Slopes

The roadway geometry beyond the edge line or edge of pavement might exhibit great diversity. Upon leaving the traveled way, a motorist might encounter a foreslope, a backslope, a transverse slope or a drainage channel which typically represents a change in roadside slope from a foreslope to a backslope, with or without a distinct bottom surface. Each one of these elements could normally have a wide range of values for their main dimensions: width, length and slope (measured along a plane that should be perpendicular to the road centerline). The height of the side slope (difference in elevation between its highest point and its lowest, measured in the same plane perpendicular to the road centerline) is also critical for RSAP analysis. It is used as a key parameter to classify the roadside slopes.

Table 4.2: Clear zone distance values for each study site

Site	Location	Basic Clear Zone Width (feet)	Adjusted Clear Zone Width (feet)
1	Riverview Drive	14	21
2	Lake Magdalene Boulevard	16	16
3	Gunn Highway (at Lutz Lake Fern)	16	21
4	Newburger Road (Near US41)	10	15
5	Newburger Road (by Cool Kell Lake)	12	18
6	Gunn Highway (at Isbel Lane, near Van Dyke)	16	22
7	Hutchinson Road	20	24
8	Countryway Boulevard	16	21
9	Hanna Road	14	21
10	Livingston Avenue	20	20
11	McIntosh Road (farthest from I-4)	14	21
12	McIntosh Road (nearest to I-4)	14	21
13	N. Dover Road	16	16
14	N. Charlie Taylor Road (near US 92)	14	14
15	Charlie Taylor Road (north of I-4)	18	18
16	Isabel Avenue	10	10
17	Mabrey Avenue	10	15
18	Nundy Avenue	12	18
19	Balm Riverview Road	20	27

These four types of roadside slopes are part of the nine categories of roadside features that need to be inventoried in each site for RSAP analysis. For each category there are many predefined “category types” used to classify each condition found in the field. Foreslopes have 54 types ranging from flat-ground to recoverable (up to 1:4 for vertical to horizontal ratio), non-recoverable and critical slopes (steeper than 1:3). A non-recoverable slope is one where the driver of an errant vehicle is unable to stop the car or to maneuver it to return to the roadway easily. The slope is traversable and vehicles are expected to reach the bottom without overturning. Vehicles running into a critical slope are very likely to overturn.

For each of these 54 category types of foreslopes RSAP has built-in equations to estimate the severity of the accident based on the estimated speed the vehicle was traveling when it left the traveled way. There are also 25 category types for backslopes, 12 for parallel ditches and 90 for intersecting slopes. Moreover, the analyst can defined more category types if able to specify the parameters needed by RSAP to compute the severity index of accidents for vehicles encountering these particular types of “user-defined” features.

The field inventory begins with a general classification of what categories of roadside slopes are present in each site. Then the location of each one along the road length is noted and measured from the starting reference point of the site. Tape measurements were taken as to its width and height. The length of the particular feature was computed as a derived measurement based on the point along the road length where the feature ceased to exist.

In the initial stages of field data collection, representative locations along the study site were selected for detailed cross-section measurement using an ad hoc procedure: a straight metal angle twenty four feet in length was marked every half a foot and it was placed perpendicular to the road edge line with one end of the metal piece in contact with it. The metal angle was then set horizontal using a carpenter’s level and vertical measurements were taken at intervals such as capturing any change of slope.

The metal angle was then moved along the same plane away from the traveled way using a reference point and keeping record of the last measurement and the first measurement in the new position to link both positions and their vertical measurements. The data so recorded on paper is then transferred to an Excel file. Once the data is digitized, a few computations can give the elevation of each off-set point with respect to the edge line. These values can be plotted easily. Figure 4.5 shows the detailed layout that this procedure is capable of achieving.

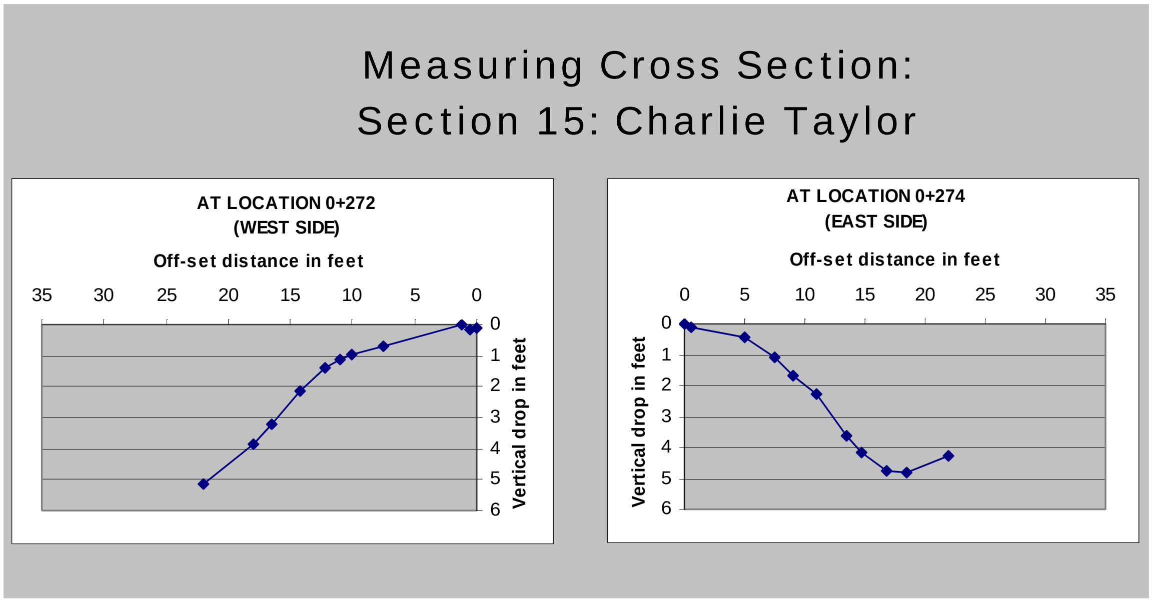

Figure 4.5: Results from a detailed cross section measurement in Section 15

The location selected for computing the roadside slope cross section had to be representative of the existing slopes and when necessary a greater number of sample locations were chosen. These results were useful to define all the parameters of the roadside slopes. However, this procedure proved to be very time consuming and somewhat dangerous for it involved stepping into tall grass and bushes. Moreover, the data gathered usually had a greater level of precision than that required for RSAP to identify the category types of roadside slopes. So the above procedure was replaced by a simpler approach.

A straight metal angle four feet in length was equipped with a device capable of measuring horizontal angles (the reading is set to zero when the metal angle is horizontal) at intervals of one degree and with highly visible marks every five and ten degrees. Figure 4.6 shows a picture of the device.

Figure 4.6: Field instrument to measure inclination angle of roadside slopes

The straight angle was then place on top of the roadside slope and perpendicular to the road center line. Several readings were taken for each identifiable distinct slope in the field. These readings were recorded in field sketches and were later used to classify the slopes for input into RSAP. It was very common to obtain different readings for a slope that looked quite homogeneous by eyesight. However, many of these diverse readings would still yield the same category type for the slope under investigation. Table 4.3 indicate the range of angle readings that would fall within a given category type as predefined in RSAP. The slope measurements were complemented with measurements of roadside slope width and height.

Table 4.3: Range of angle readings used to categorize a descriptive slope into RSAP

Descriptive Slope	**Descriptive Slope in Percentage**	**Corresponding Angle of Inclination (degrees)**	**Range of Acceptable Readings for the Slope Angles (degrees)**
Flat	0%	0.0	< 4
10 to 1*	10%	5.7	5 – 6
8 to 1	12.5%	7.1	7 – 8
6 to 1	16.7%	9.5	9 – 11
4 to 1	25%	14.0	12 – 15
3 to 1	33%	18.4	16 – 20
2 to 1	50%	26.6	21 – 30
1.5 to 1	66.6%	33.7	30 – 40
Vertical	n.a.	90.0	> 40

* 10 to 1 describes an slope that drops or raises one vertical unit for every ten horizontal units

This same device was used to measure the angle of the transverse slopes. These slopes are referred to as intersecting slopes in RSAP, and are commonly found in driveways. Of higher dimensions they can be found in drainage elements such as “boxculverts” either across the road under study or on intersecting roads.

4.8 Roadside Features: Fixed Objects

The most omnipresent roadside features are roadside slopes because, as it has been discussed above, they are an integral part of the clear zone concept. Ideally, these roadside slopes should be free of any other obtrusive roadside feature, especially when they are traversable. Good engineering practice requires that all obstacles be removed from recoverable slopes. However, in practice, this is not always possible. As a matter of fact, many roadside signs are placed adjacent to the road. Consequently, alternative solutions need to be found.

All recent editions of the Roadside Design Guide (*5*, *6*, *7*) lists the following alternatives that could be evaluated for a given situation with regard to obtrusive roadside features:

- Remove the obstacle
- Redesign the obstacle so it can be traversed safely
- Relocate the obstacle to a point where it is less likely to be struck
- Reduce impact severity by using an appropriate breakaway device
- Shield the obstacle with a longitudinal traffic barrier or crash cushion or both
- Delineate the obstacle if the above alternatives are not appropriate

These same basic alternatives are applicable to drainage structures and in general they are valid as general guidelines for any roadside safety improvement project.

In essence RSAP, as used in this project, evaluates the risk associated with the prevailing conditions in the roadside environment of each site to determine the best course of action in each case considering that available funds are limited and that a choice must be made as to which sites require immediate attention.

The field data collection effort on the roadside environment was designed to provide RSAP with the location, nature and dimensions of existing features classified in the way the program needs them.

For any fixed object, the analyst must provide the following:

- Location
- Off-set
- Width
- Length

The location identifies whether the object is on the right of left side of the road and its distance from a reference starting point at the beginning of the study section (first segment). For sites not having horizontal curves, objects on both sides need to be identified but there should be only one starting point that can be at either end of the study section. The distance measurements were taken as the nearest contact point in the longitudinal direction between incoming vehicles traveling on the same side of the road where the object is located. Figure 4.7 represents this procedure.

The off-set is the distance (feet plus inches) from the outside of the edge line to the object’s nearest contact point along a horizontal line in a plane perpendicular to the road center line. Figure 4.8 details how the measurement is taken. For RSAP analysis, width of a fixed object is its dimension perpendicular to the road centerline while length is its corresponding dimension in an axis parallel to the longitudinal axis of the road.

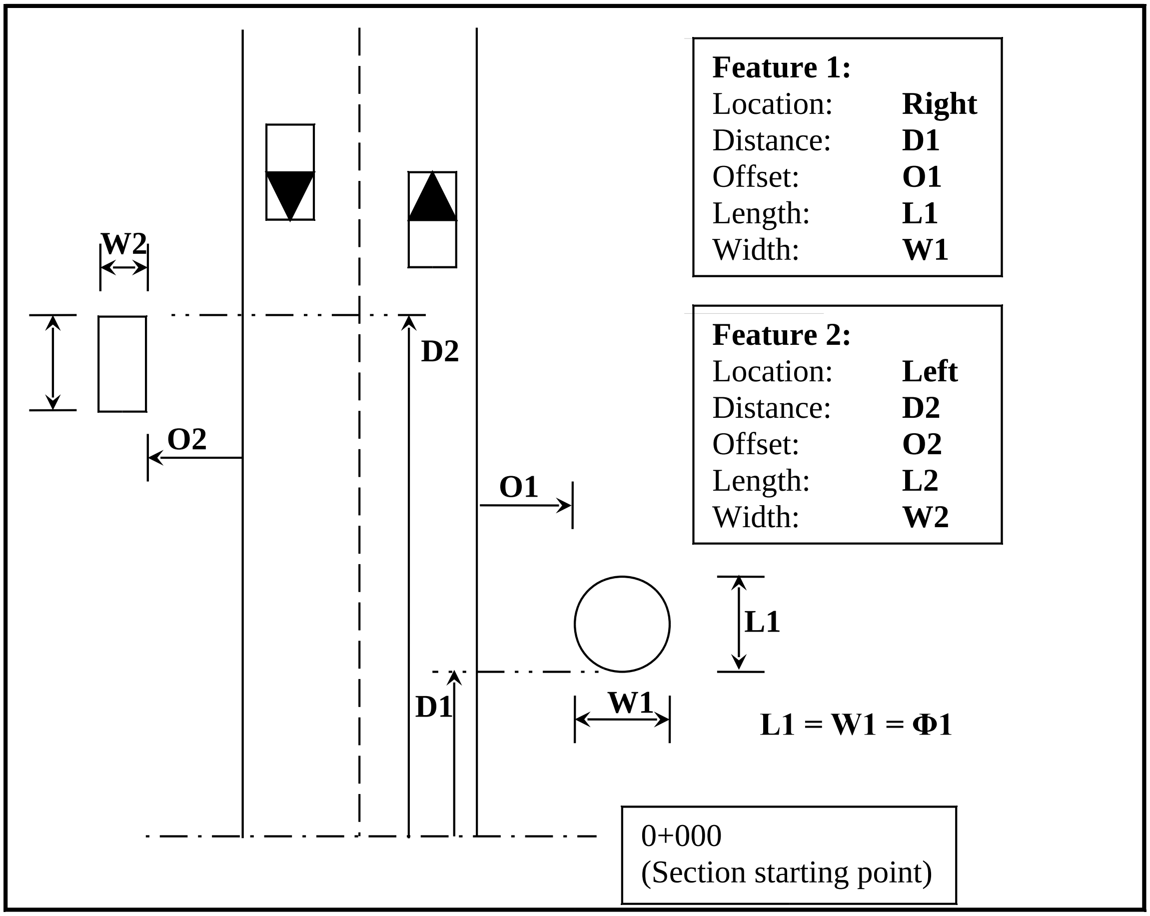

Figure 4.7: Proper distance measuring for locating roadside features

4.8.1 Trees

Between 1993 and 1999, single vehicle crashes with trees accounted for nearly 25 percent of all fixed-object fatal crashes annually and resulted in the death of more than 3,000 persons each year (*5*). The data for fixed-object fatalities in 2008 (*7*) indicates that the participation of trees was 48%.

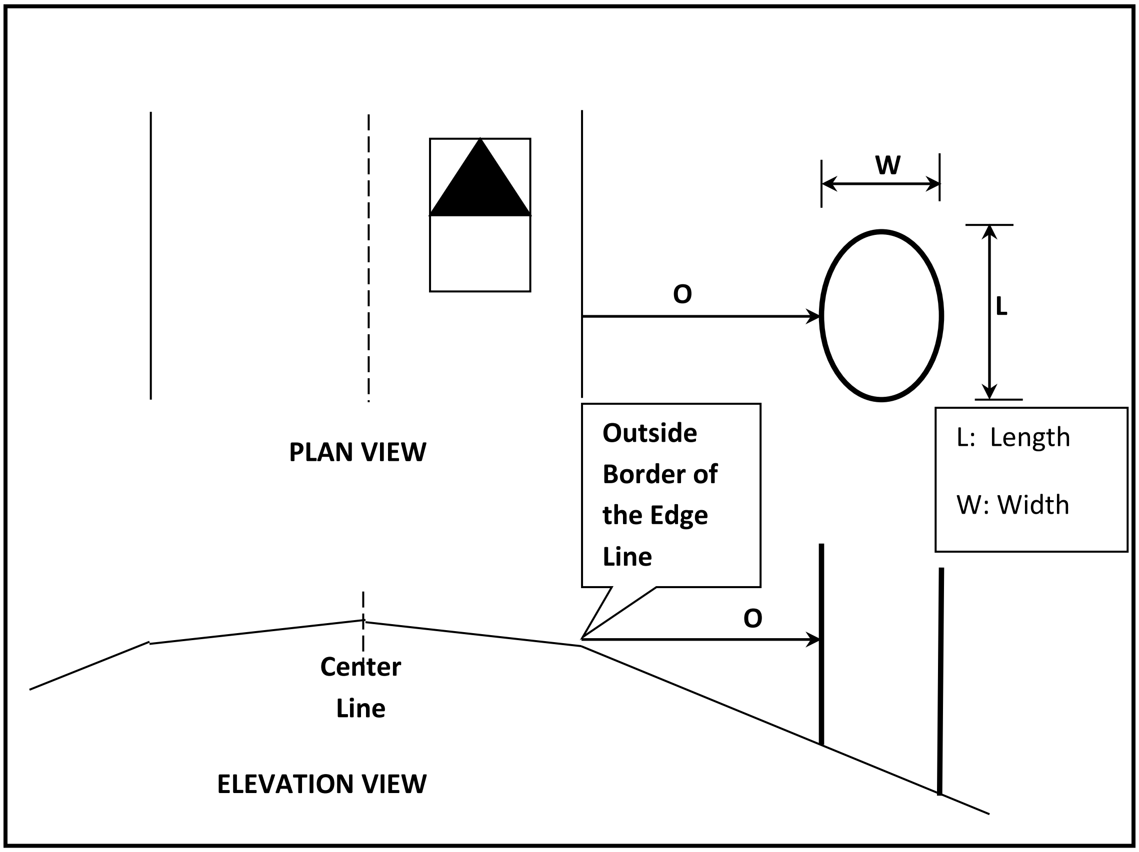

Figure 4.8: Proper measuring of the off-set distance

In a road network like the one in Hillsborough County, trees represent the most frequent type of fixed objects. Some of them are at a considerable and safe distance from the pavement edge, but some of them—especially in local roads—are very close to the travelled way. There are seven tree sizes in RSAP's default category types, ranging from 2 inches to 12 inches in diameter in increments of 2 inches, and then a final category type for trees of more than 12 inches in diameter.

In general the width and length of trees were equal to the measured diameter. Most trees have symmetrical diameters in all directions but some of them have elongated cross sections. In these cases, the width and length were taken as the projected axis according to the tree orientation with respect to the road centerline.

All diameter measurements were made using a flexible tape to measure the circumference to then compute the diameter or by measuring the projected (estimated) diameter. All measurements were taken at four and half feet above the ground except in cases where branches had already developed at this height (*8*).

In those cases measurement were taken between one and three feet above ground under the assumption that this was the most likely point of contact. The upper bound of three feet was used mainly in steeper slopes. Diameters were calculated or measured to the nearest tenth of an inch and recorded to the corresponding category in increments of one inch. As an example, trees with an estimated diameter between 5.6 inches and 6.5 inches would be assigned a value of 6 inches when the information was recorded.

Another case found in the field was that of several tree trunks growing so close together as to become one unique fixed object for the purpose of RSAP analysis. For these cases, the individual diameters (d_i) were measured and an equivalent cross-section tree diameter (d_e) was computed by means of the equation:

$$\boxed{d_e = \sqrt{\sum_{i=1}^{n} (d_i)^2}} \tag{4.1}$$

The off-set distance between the edge line and the trees found during this field inventory had quite a disperse distribution as indicated in Figure 4.9.

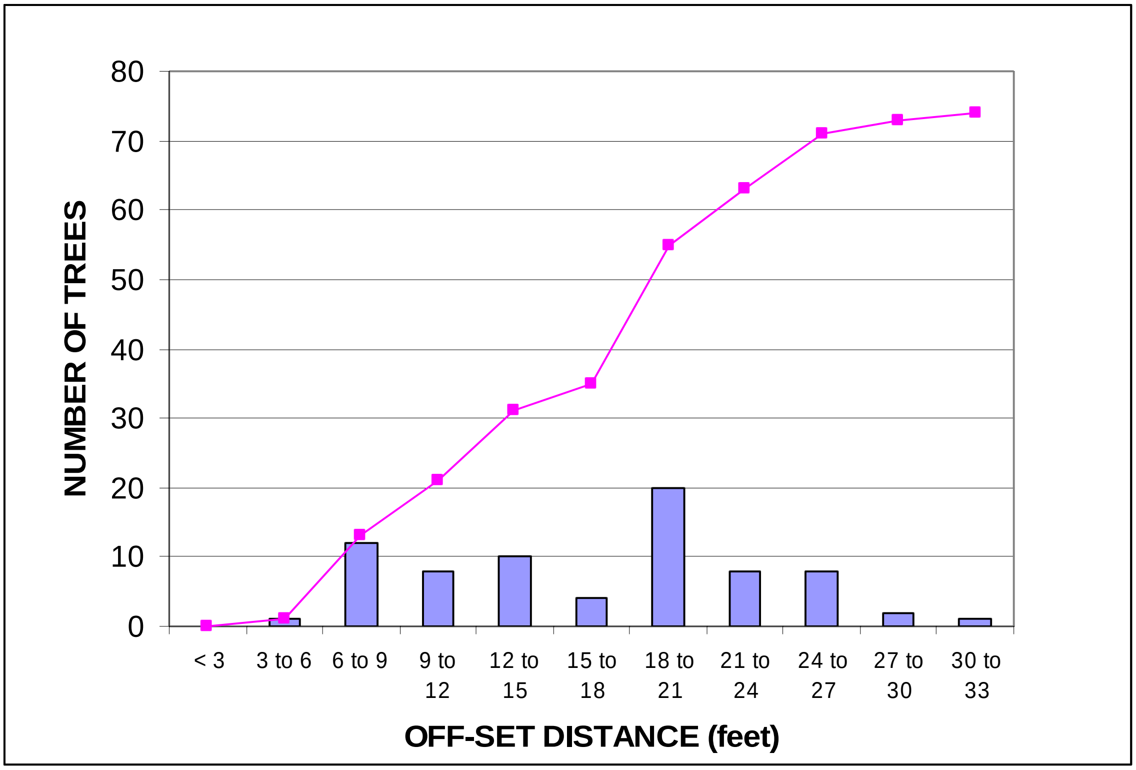

Figure 4.9: Overall presence of trees and their lateral distribution

4.8.2 Utility Poles

Between 1993 and 1999, motor vehicle crashes with utility poles accounted for approximately 10 percent of all fixed-object fatal crashes and resulted in the death of more than 1,000 people each year (*5*). The data for fixed-object fatalities in 2008 (*7*) indicates that the participation of utility poles was 12%. This degree of involvement is related to the number of poles in use, their proximity to the traveled way, and their unyielding nature.

Practically all utility poles are made of wood and have a circular cross section. RSAP has four category types of wooden utility poles: 8, 10 and 12 inches in diameter, in addition to those with diameter greater than 12 inches.

The location of utility poles is a simplified application of the procedures described for trees in the previous section. It is worth mentioning, for the sake of completeness, that section 8 had some light poles made of concrete and with a square cross section. These were classified as rectangular fixed objects category type 8 (width equal to 1.5 feet and height greater than 3 feet) but their real width and length were measured and input into RSAP.

In this field inventory it was found that the off-set distance of the utility poles to the edge line exhibited the distribution indicated in Figure 4.10.

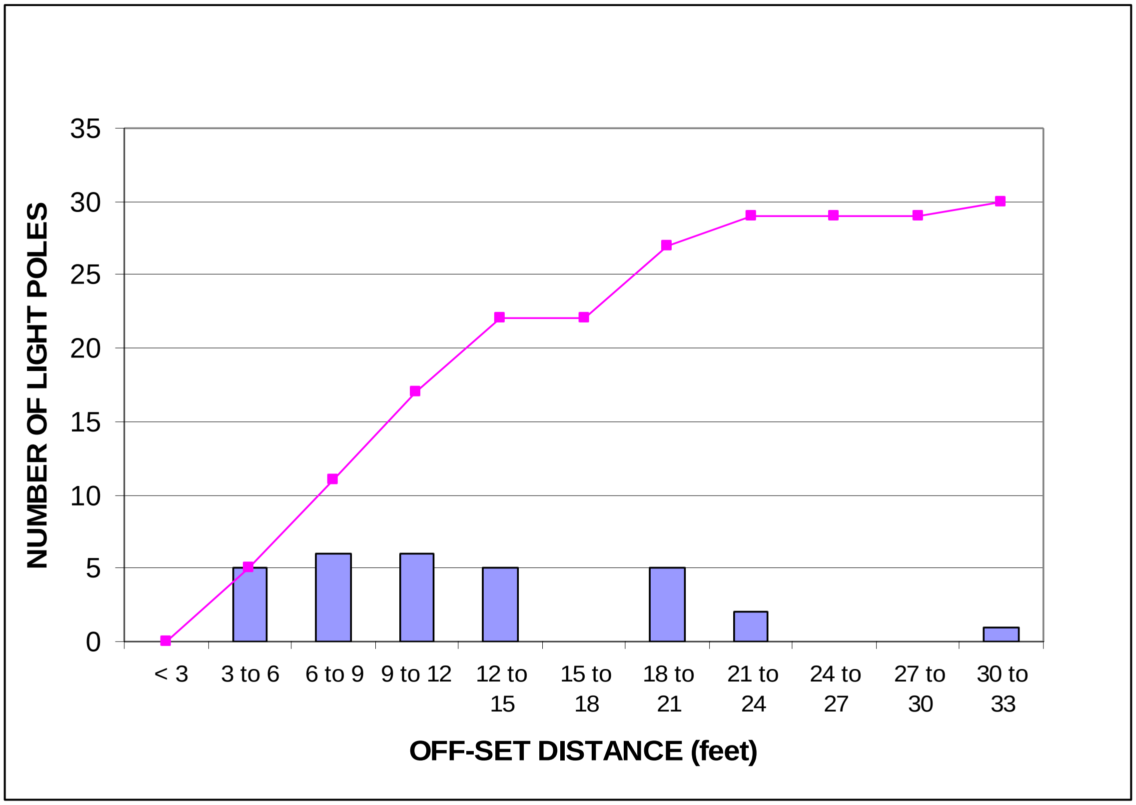

Figure 4.10: Overall presence of utility poles and their lateral distribution

4.8.3 Curbs

Considering their shape and their dimensions, there are many different types of curbs as indicated in AASHTO's Green book (*3*). RSAP does not have any particular category for curbs but they should be classified as fixed objects provided that their height is greater than four inches. Most of the curbs found in this field inventory were six inches height. For analysis purposes they were classified under category type 5 which refers to rectangular objects with height equal to six inches. The width dimension is not clearly defined for curbs and a value of 0.6 foot was used throughout.

4.8.4 Walls

There were a few sites with fencing walls alongside the road section under study. These were made of concrete blocks. For RSAP analysis they were classified under category type 8 for their height was always greater than three feet. The definition of their width was a function of their layout with respect to the edge line of the road. In most cases where they had no perpendicular component, the width input was equal to the actual thickness of the wall.

True rectangular fixed objects were found in sites 15 and 13. These were more like bridge railings or, more properly culvert headwalls, intended to prevent vehicles from running off the edge of the culvert. They were made of concrete and their corresponding locations and dimensions were input into RSAP.

4.8.5 Small Roadside Traffic Signs

All sites had small traffic signs of one sort or another. Sites having horizontal curves were populated with “chevron” signs to alert drivers of the alignment. Speed signs—regulatory and advisory—were posted in all but one site, and other warning signs were recorded during the field inventory. A few signs were of the multiple post type, having more than one support within seven feet spacing (*5*).

Typically these signs are located about five feet from the edge line. The cross section of their support post is typically a standard structural element with a very small foot print. For RSAP analysis they were input as having dimensions of .3 by .3 feet.

All of these small traffic signs were assumed to be of the breakaway support type although no specific information was obtained about their characteristics. There are five category types for this kind of supports varying in their “Delta V” values, which refer to the contact speed of an errant vehicle that would result in the shear stress that would activate the breaking mechanism. These values range from 5 to 25 feet per second (fps) in increments of 5 fps, equivalent to contact speeds from 3.4 to 17.0 mph. The lowest value was input into RSAP for all small signs found in the field inventory.

4.8.6 Repetitions and Flare Rate

These are two very useful input options in RSAP that were hardly used and not used at all during this data collection effort but which are important to present for the sake of completeness and because they will be used in other applications of the data here presented or in future research.

“Repetitions” was used in Site 19 where there were a series of wooden post creating a fence in the clear zone of the horizontal curve. RSAP needs to know how many identical units there are and what their (assumed regular) spacing is.

“Flare Rate” was not used at all but it refers to a continuous fixed object along the road but which is not parallel to the edge line. RSAP needs to know if the object becomes closer to the edge line in the direction of traffic—referred to as “upstream” flare—or if the flare is “downstream” (meaning that the upstream end is closer to the edge line than the downstream end). RSAP also needs the actual flare rate which is defined as the ratio of lateral distance over longitudinal distance.

4.9 Roadside Features: Culvert Ends

Drainage elements are critical components for the adequate structural performance of a road system. However, their existence also plays a role in the operational performance for a particular road segment: these elements need to be maintained and these periodic maintenance activities may cause traffic disruptions increasing the potential for crashes. On top of this, the maintenance personnel are exposed to the prevailing traffic conditions while performing their work. All these aspects should be part of the design engineer’s considerations when defining alternative improvements for roadside safety projects.

During the field data collection, the emphasis was on the detailed location of the end elements of culverts as required by RSAP. Five different categories of culvert end types are given (A, B, C, D, and E, based on the angle of the wing walls with the longitudinal axis of the drainage structure). Each one is further classified in seven category types based on the height of the vertical drop introduced by the culvert end in the side slope. The predefined heights are 1, 1.5, 2, 3, 4, 6, and 8 feet.

Similar to other roadside features, culvert ends are located based on their closest points to the approaching vehicles.

4.10 Sensitivity of RSAP to Additional Roadside Features

The field data collection undertaking for this project was very detailed and comprehensive. All roadside features that existed along the road were inventory on both sides of the road for sites on tangents sections and on the outside of the curve for sites having a horizontal curve.

Most of these features were relevant as roadside features in the RSAP analysis and a few of them were only collected for the purpose of completeness (while in the initial stages of the effort) and for referencing along the road. Trees were thoroughly inventoried and this required additional time and considerable greater effort for those located further from the road.

In cases where the boundaries of the right of way were clearly marked with a fence, the fence itself marked the end of the inventory in the across-the-road direction. No data was collected more than 82 feet away from the traveled lane because this is RSAP's current maximum extent for lateral encroachment (25 meters). Most efforts were concentrated in locating features within the "modified clear zone" width computed for each location. This value (presented in Table 4.2) was taken as a reference mid-point limit that would help in delineating the limits, not necessarily strictly enforcing them.

However, even while having these considerations in mind, the question remained as to whether more data than necessary was being collected, if all of the collected data would be entered as input into RSAP, and what the program would do with it. More importantly, there was the question of addressing the issue of what differences in results would be obtained if additional feature data were input.

To answer this question it is very important to understand thoroughly how the impact computation procedure is done by RSAP. In general, the closer the feature is to the traveled way, the more important it is to record it because the likelihood of the feature being involved in a crash is very high.

All roadside features have some severity index (SI) associated with them. In RSAP, even flat ground would yield a SI of 0.47 if the encroached vehicle is traversing it at a speed of 60 mph. Although any errant vehicle under this condition would only experiment property damage level one (PDO1), the cost of such an encroachment would be $625 that would possibly cover for damaged tires, shock absorbers and alignment. The SI would increase as the roadside slope becomes steeper as illustrated in Figure 4.11.

The extension of the lateral encroachment also increases with increasing gradients of the roadside slope as indicated in Figure 4.12. Moreover, RSAP computes the change in potential energy and transforms it into additional vehicle speed. Consequently, roadside features located near the bottom of a steep roadside slope should be carefully inventoried for the analysis.

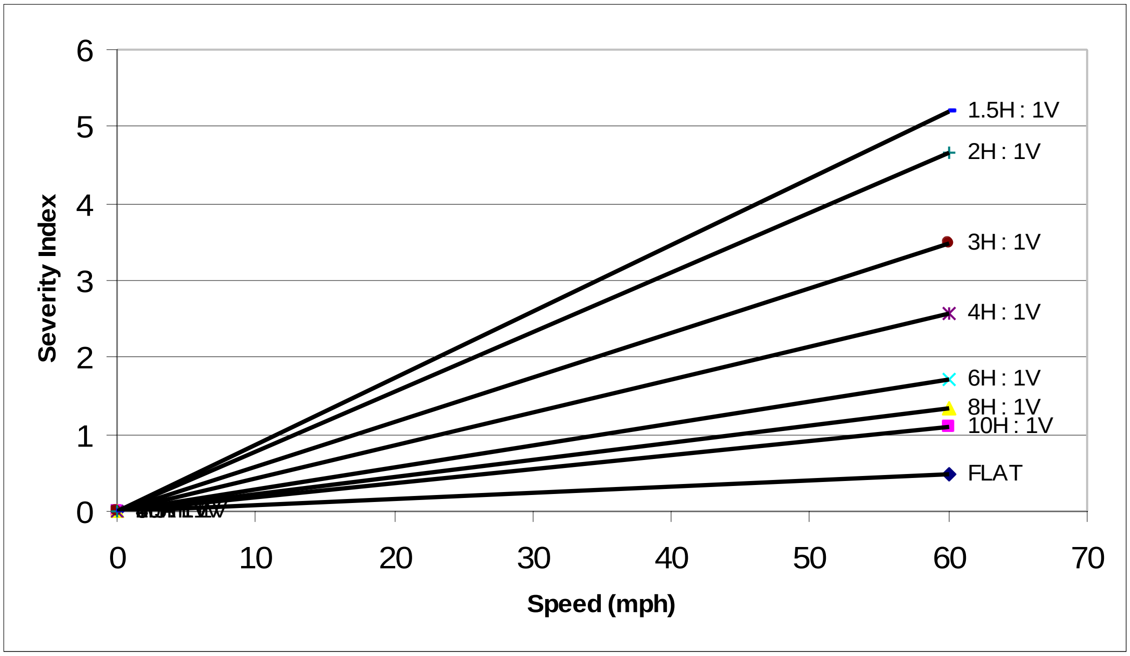

Figure 4.11: Severity Index as a function of roadside slope. (foreslopes, small to medium drop)

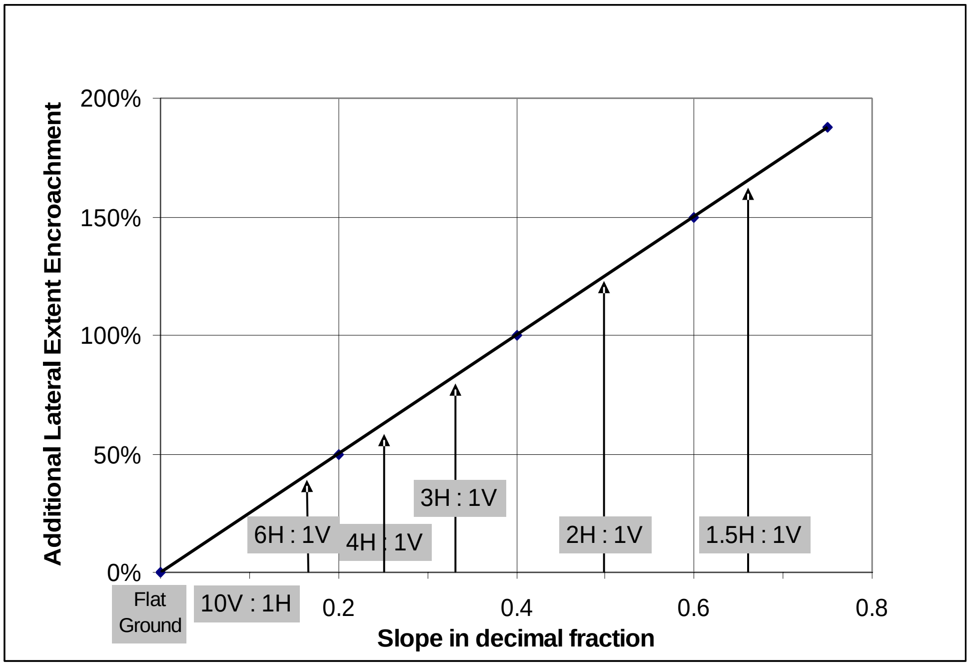

Figure 4.12: Additional percent increase of lateral extent with roadside slope

Another important aspect to consider when performing the field inventory is the relationship between frontal and depth density of roadside features. Frontal density is critical for impact analysis: the more features there are in “front row”, the higher the chances for an errant vehicle to hit these objects. On the other hand, features hidden behind other objects will only be struck if the vehicle penetrates the features in front. This will happen only if the feature first struck is of a breakaway design, or if it is a traffic barrier with known energy absorption capacity or containment index.

Two more possibilities should be considered when deciding if roadside features hidden behind other features are worth the extra effort needed during field surveys. One is in the case of a rollover. In the current version of RSAP, that would happen only for certain types of vehicles (not for automobiles and light trucks that generally make more than 80% of the total vehicle fleet and probably a higher percentage of vehicle miles in county roads) and only in case of the front feature being a longitudinal barrier.

Even if there is a rollover and the vehicle hits the object behind the barrier after overturning, the most severe impact is going to be the one used for computations by RSAP and it is highly probable that it will be the rollover.

The second possibility has a higher probability of occurrence: a vehicle may run off the road at a location and at an angle such that places the further off roadside feature (the one having the same longitudinal coordinate but a greater off-set distance value than—and consequently hidden by—the one in front) within the vehicle’s hazard envelop as defined by its assumed straight path and the vehicle’s dimensions. Figure 4.13 shows an illustration of this case.

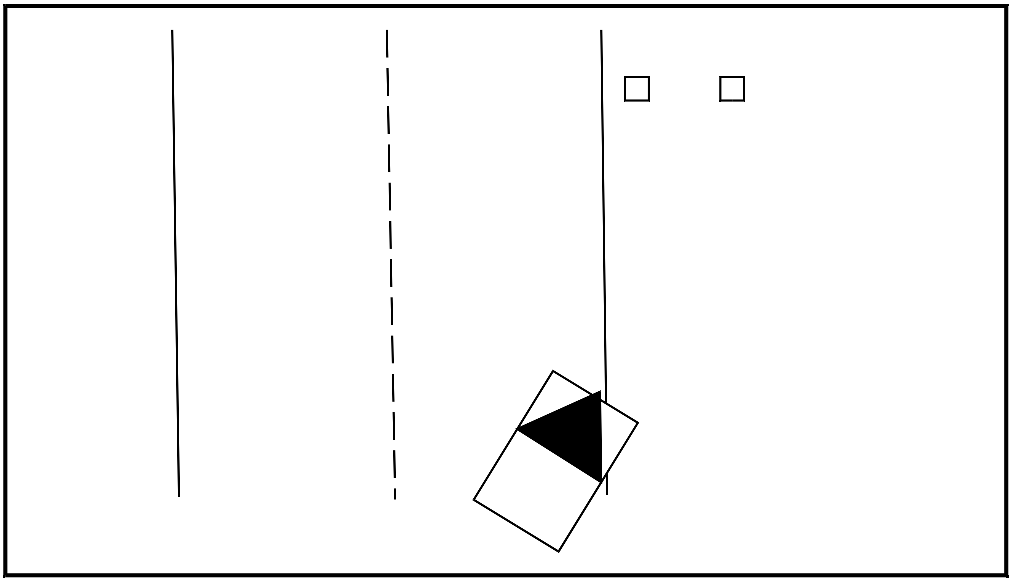

Figure 4.13: Two roadside features with same longitudinal distance but different off-set values

In these situations, and to be on the safe side, the best decision for the field personnel is to collect the location and characteristics of such features, unless they are completely enclosed by other features.

Finally, if there are several roadside features (of similar nature, i.e. category in terms of RSAP) so close together as to represent a single compact object of bigger size, they might be recorded as a single item of equivalent dimensions. Figure 4.14 shows an example using trees and equation 4.1 presented in section 4.8.1 to determine the equivalent diameter.

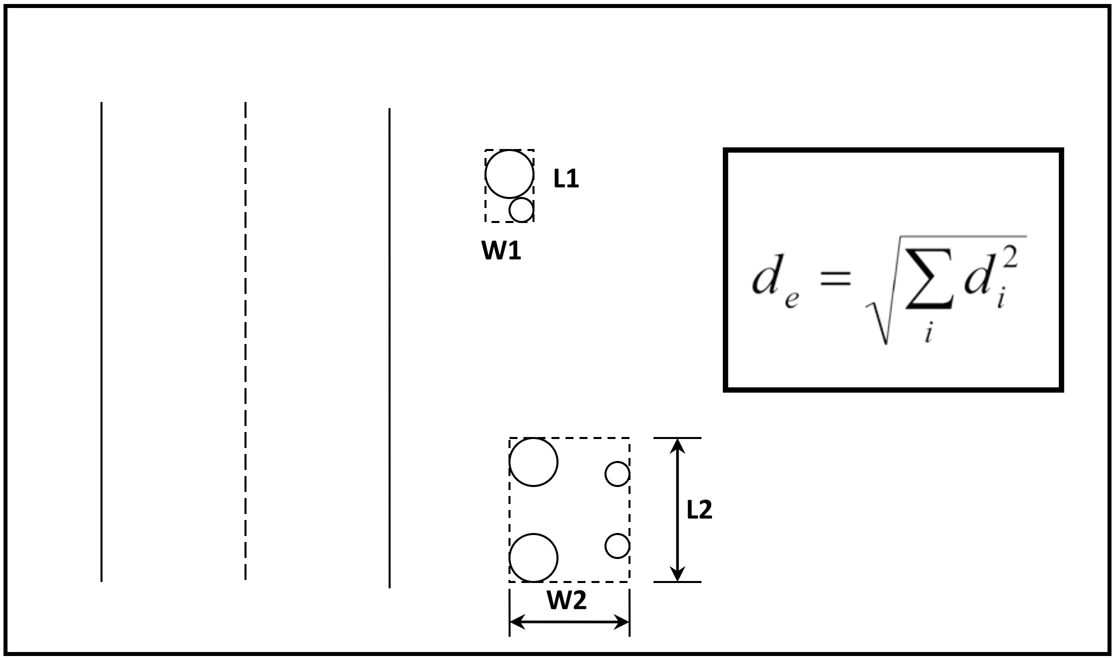

Figure 4.14: Several roadside features so close together as to be considered as a single feature

4.11 Data Reduction

All the data elements described in the previous sections were collected for each study site using “hand drawing” diagrams as the one presented in Figure 4.15. These detailed drawings were prepared in the field with the aid of previous information collected in the office and during preliminary site visits.

Before reaching the data reduction process, some sort of data manipulation needs to take place. By data manipulation it is meant the transformation of all the detailed data collected in the field into suitable data as required for RSAP for analysis.

Once the analyst has arrived to a numerical value that could represent the variable needed by the model, this values is input as an ASCII computer file using RSAP’s friendly User Interface Program.

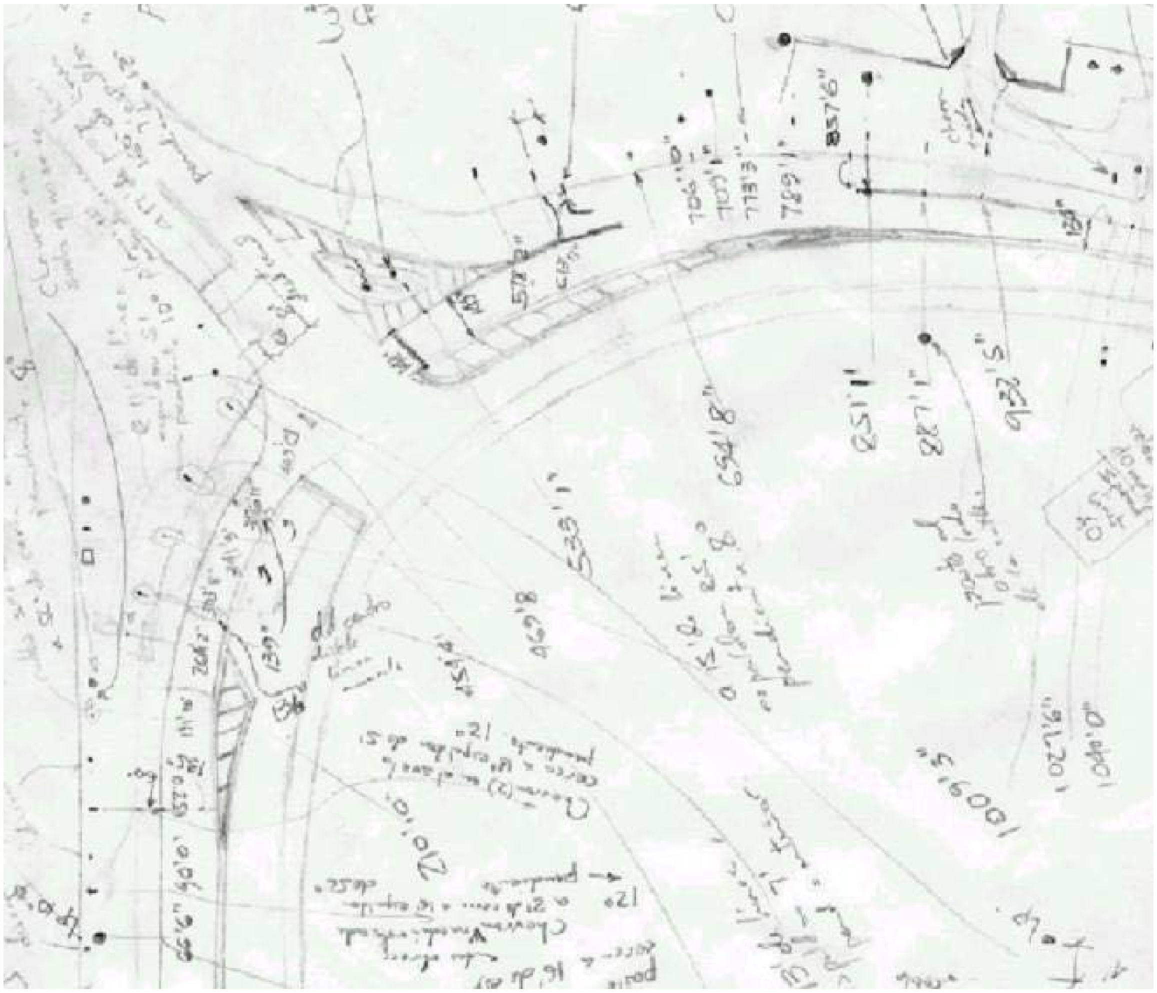

Figure 4.15: Field hand-sketch detailing road characteristics and roadside features

4.12 Traffic Data

Traffic volume is a key variable for RSAP analysis. As an overall value, it is first used to determine the expected annual number of encroachments in a given road segment. The different vehicle types are then used in the simulation process to determine the likelihood of a rollover. Moreover, traffic growth will have a compounding effect over the years of the analysis period.

Consequently, the analyst must provide three sets of data with regard to traffic. The first one is the ADT or Average Daily Traffic representative for each study site. This value is assumed to remain constant for the full first year of the analysis period. RSAP assumes that the traffic volume splits evenly in both directions of traffic.

The traffic volumes used in this analysis were obtained from the June 2004 publication "Level of Service" (*2*) published from the Traffic and Growth Management group of the Transportation Division and available from the County's Web Site. Eight of the nineteen sites had no published values. For these locations, 2003 estimates were derived from other databases available (particularly Hansen, administered by the County's Fiscal and Administrative Services) from the Public Works Department. Table 4.4 presents the traffic volumes used in this analysis and their source.

Another important piece of important regarding traffic data is the vehicle composition mix because different vehicle types have dissimilar propensities to overturn. However, this level of detail on traffic data was not available for all the sites and at this time, for this ranking exercise, it was not considered critical. Consequently, RSAP's default distribution—based on a 10% of trucks—was used. Table 4.5 presents the default values applied to all study sites. If more detailed information is available, the analyst can introduce the percentage values for each vehicle type.

Finally, the expected overall traffic growth (same for all vehicle types) over the entire analysis period is required. This variable was not relevant for the analysis conducted in this project because the focus was on the evaluation of the current risk which is assessed under existing roadside conditions and levels of traffic. This is equivalent to say that the analysis period is one year.

Table 4.4: Traffic volumes for each study site with source data

Site	Location	Traffic Volume (vpd)	Source of Information
1	Riverview Drive	5,404	T&GM Report*
2	Lake Magdalene Boulevard	6,585	T&GM Report
3	Gunn Highway (at Lutz Lake Fern)	17,950	T&GM Report
4	Newburger Road (Near US41)	553	Hansen**
5	Newburger Road (by Cool Kell Lake)	901	Hansen
6	Gunn Highway (at Isbel Lane, near Van Dyke)	22,800	T&GM Report
7	Hutchinson Road	14,314	T&GM Report
8	Countryway Boulevard	12,611	T&GM Report
9	Hanna Road	713	Hansen
10	Livingston Avenue	11,003	T&GM Report
11	McIntosh Road (farthest from I-4)	4,061	T&GM Report
12	McIntosh Road (nearest to I-4)	4,061	T&GM Report
13	N. Dover Road	6,600	T&GM Report
14	N. Charlie Taylor Road (near US 92)	1,109	Hansen
15	Charlie Taylor Road (north of I-4)	3,920	Hansen
16	Isabel Avenue	436	Hansen
17	Mabrey Avenue	317	Hansen
18	Nundy Avenue	779	Hansen
19	Balm Riverview Road	8,250	T&GM Report

* T&GM Report: Traffic and Growth Management group, Level of Service Report, June 2004
** Hansen: Hillsborough County’s Fiscal and Administrative Services, Hansen Database. 2003 Estimates

Table 4.5: RSAP's default traffic composition mix used in this project

Vehicle Group	Vehicle Type	Category	% in Vehicle Mix	% in Vehicle Mix	% in Vehicle Mix
Passenger	Passenger Car	Small	8.1	54.0	90.0
		Intermediate	33.8		
		Large	12.1		
	Pickup and Van	Small Pickup Truck	9.4	36.0	
		Mini-Van	12.6		
		Full-size Pickup Truck	10.4		
		Specialty Vehicle	3.6		
Cargo	Single Unit Truck	Empty	2.8	4.0	10.0
		Loaded	1.2		
	Tractor-Trailer	Empty	1.2	6.0	
		Van-Trailer Loaded	3.6		
		Tank-Trailer Loaded	1.2		

4.13 References

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3. AASHTO. *A Policy on Geometric Design of Highways and Streets. Fifth Edition*. American Association of State Highway and Transportation Officials, Washington D.C., 2004.

4. AASHTO Task Force on Traffic Barrier Systems. *Guide for Selecting, Locating, and Designing Traffic Barriers (Yellow Book)*. American Association of State Highway and Transportation Officials, Washington, D.C., 1977.

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6. AASHTO. *Roadside Design Guide, 3rd Edition 2006, with updated Chapter 6*. American Association of State Highway and Transportation Officials, Washington, D.C., 2006.

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8. Blinn, C. R., and T. E. Burk. Estimating Tree Diameter. In *Measuring Timber in the Private Woodland*, University of Minnesota Extension Service, 1998. http://www.extension.umn.edu/distribution/naturalresources/components/DD3025-03.html. Accessed May 1st, 2004.

CHAPTER 5: DATA ANALYSIS AND RESULTS

5.1 Building the Database

The data collected for each of the 45 segments was prepared for input into RSAP for the analysis of run-off-road accidents. For each of the 45 RSAP runs, the output is delivered on the screen for review and it can be saved as a PDF file (*1*). These files were accessed through Adobe Acrobat Pro (*2*) and saved as individual Excel files for data manipulation to avoid manual input that could be more error prone. A master file was created in Excel (*3*) with all the desired variables for the analysis and then it was read into the statistical analysis package SPSS Version 19 (*4*).

The most relevant data generated by RSAP is the expected annual crash frequency for each of the features that existed in the roadside environment of each segment. The program also computes the average severity for the computed accidents that involved that particular feature in a given year and the corresponding annual crash cost.

The program is capable of analyzing several segments that jointly form a continuous study site. For the analysis performed for this research, each run had only one segment to obtain a better understanding of the key variables involved in the results.

For each run the program provides two additional summary results: the total crash cost for the segment and the total expected crash frequency in number of accidents per year. Table 5.1 presents the name and description of the variables that were included in the database for analysis in this project.

Table 5.1: Variables used for analysis in this research

Variable Name	Variable Type	Decimal places	Description
SITE	Numeric	0	Study site ID as of the original project
SEGMENT	String	0	Segment ID linked to the Site.
AREATYPE	String	0	Rural or Urban
FUNCT_CLASS	String	0	Functional class of the road
HWY_TYPE	String	0	Highway type: divided or undivided
SEG_LENGTH	Numeric	0	Length in feet of the study segment
SPEED	Numeric	0	Posted speed in miles per hour
ADT	Numeric	0	Average daily traffic in vehicles per day
LANES	Numeric	0	Number of lanes in the study segment
LN_WIDTH	Numeric	1	Lane width in feet
SH_WIDTH	Numeric	1	Shoulder width in feet
CURV_RADIOUS	Numeric	0	Radius of Curvature in feet (=10,000 if no curve)
SEG_TY_CRASH_FREQ	Numeric	6	Expected Annual Crash Frequency for the segment
SEG_Y_COST	Numeric	2	Annual Crash Cost for the segment in dollars
FEAT_UNIK	String	0	Feature identification as per RSAP run linked to the segment ID
FEAT_CLASS	String	0	Feature group defined by the user for analysis
FEAT_SUBCLASS	String	0	Feature group defined by the user for analysis
ID	Numeric	0	Feature identification as per RSAP run linked to the segment ID
FEAT_TYPE	String	0	Feature basic classification as per RSAP
FEAT_CLASSIFACTION	String	0	Feature detailed classification as per RSAP
F_LENGTH	Numeric	1	Feature length in feet
F_WIDTH	Numeric	1	Feature width in feet
F_OFFSET	Numeric	1	Feature offset in feet
F_LOCATE	Numeric	1	Feature location (in feet) from start of the segment
F_CRASH_FREQ	Numeric	6	Feature expected crash frequency in accidents per year computed by RSAP
F_SEVERITY	Numeric	4	Average severity of the accidents involving this feature
F_COST	Numeric	2	Annual crash cost of the accidents involving this feature in dollars
F_AREA	Numeric	2	Feature area computed as length times width
F_LandW	Numeric	1	Feature length plus its width (half perimeter)
F_COV_AREA	Numeric	4	Ratio between feature area and length of segment
F_COV_LandW	Numeric	4	Ratio between feature half perimeter and length of segment

The analysis period selected for this research was one year. Correspondingly, the segment crash frequency and crash cost are simple additions over all the features that exist in the study segment. There were a total of 45 study segments and 337 features analyzed in this research.

5.2 Characterization of the Research Study

In this section a summary of the key variables that provide a characterization of the research study is given. Figure 5.1 shows that out of the total 45 study segments, 7 of them correspond to roads that are functionally classify as “minor arterials” roads while the remaining 38 segments are almost evenly split between local and collector roads which is quite reasonable for a study on rural roads such as this.

Moreover, as it can be seen in Figure 5.2, only two study segments are classified as divided highway meaning that in these two segments there exist a built median separating traffic in opposite directions. A review of the database would show that only those two segments have four lanes, two in each direction separated by the existing median. Consequently, most of the results obtained are for undivided highways having one lane in each direction of traffic.

Table 5.2 shows summary statistics for the remaining key variables: segment length, speed, ADT, lane width, curvature, expected annual crash frequency and crash costs. This table clearly indicates that most segments are rather safe having practically no accidents and a very low annual crash cost as indicated by the values in its last row.

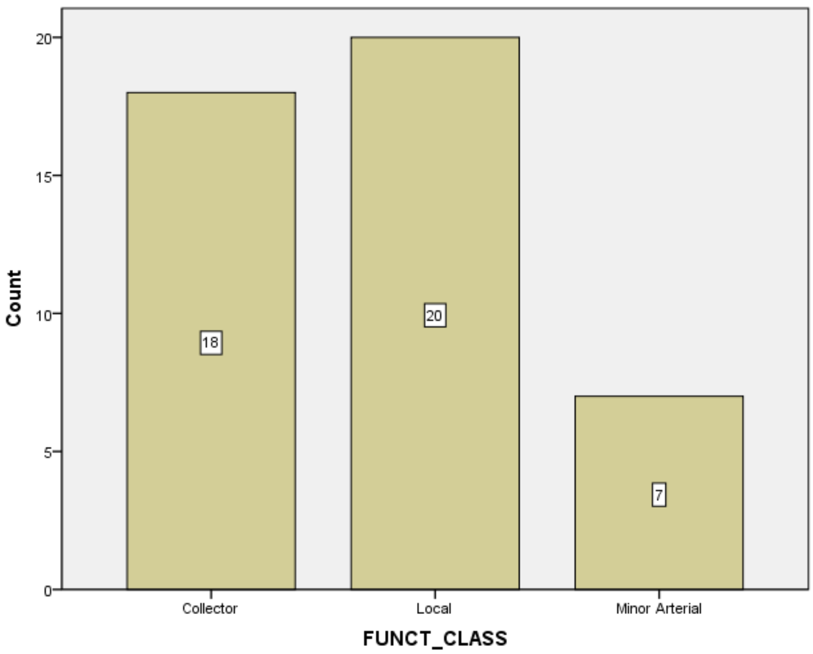

Figure 5.1: Number of study segments by road functional classification

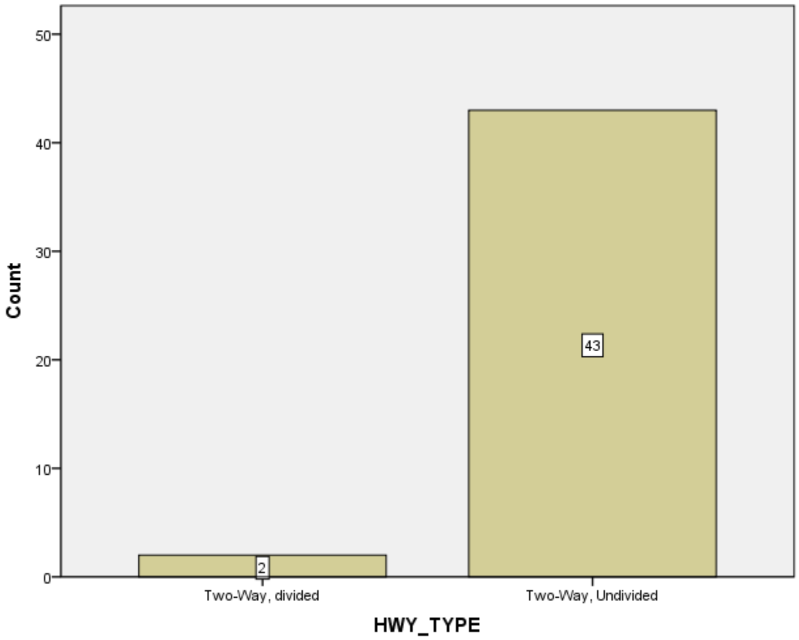

Figure 5.2: Number of study segments by highway type

Table 5.2: Summary statistics for key variables of the study segments

	Mean	Median	Std. Deviation	Maximum	Minimum	Range	N
SEG_LENGTH	238.6	160.0	198.21	949	39	910	45
SPEED	29.4	30.0	8.9	45	15	30	45
ADT	6998.36	4447.00	6557.502	22800	317	22483	45
LN_WIDTH	10.624	10.500	.9364	12.5	8.0	4.5	45
SH_WIDTH	.31	.00	1.104	5	0	5	45
CURVATURE	478.8	400.0	316.5	1050	200	850	13
SEG_TY_CRASH_FREQ	.062755	.055030	.0533360	.2307	.0086	.2221	45
SEG_Y_COST	418.10	15.59	965.62	3810.74	.11	3810.63	45

On the other hand, there are a few segments whose characteristics and nature of their roadside environment result in much higher annual crash costs. This result is totally consistent with the findings of the original project executed for Hillsborough County (*5*) where the results of the RSAP analysis were used to provide a ranking as to which ones were the most dangerous sites that warranted a more detailed study for engineering design. See Figure 3.1 in Chapter 3.

In this new research the aim is to look into the characteristics of the roadside environment that can lead to the development of relationships to predict the annual crash cost for different roadside features. These relationships could further be refined and used to classify the links of an entire rural road network to determine where to allocate more resources for roadside safety.

5.3 Characterization of the Roadside Environment

RSAP uses nine classifications to accommodate all features found in the roadside environment. These classifications are:

- Foreslopes
- Backslopes
- Parallel Ditches
- Intersecting Slopes
- Fixed Objets
- Culvert Ends
- Longitudinal Barriers
- Terminal and Crash Cushions
- Miscellaneous

There is also the possibility to create a user-defined feature. In this research only the first six categories were found as part of the roadside environment of the study segments. There were a total of 337 features. Figure 5.3 illustrates its distribution. There are just a few backslopes as expected for flat terrain conditions that prevail in the study area. The number of fixed objects is also to be expected for rural roads.

However, it is not only the sheer number that counts for accidents. Figure 5.4 indicates the crash cost distribution of these same features in this study. Again it can be seen that the effect of backslopes should not be further pursued in this study. It will probably be a relevant variable in other terrain types but in this study its effect is negligible. At the same time it can be seen that intersecting slopes deserves careful attention while parallel ditches do not as much.

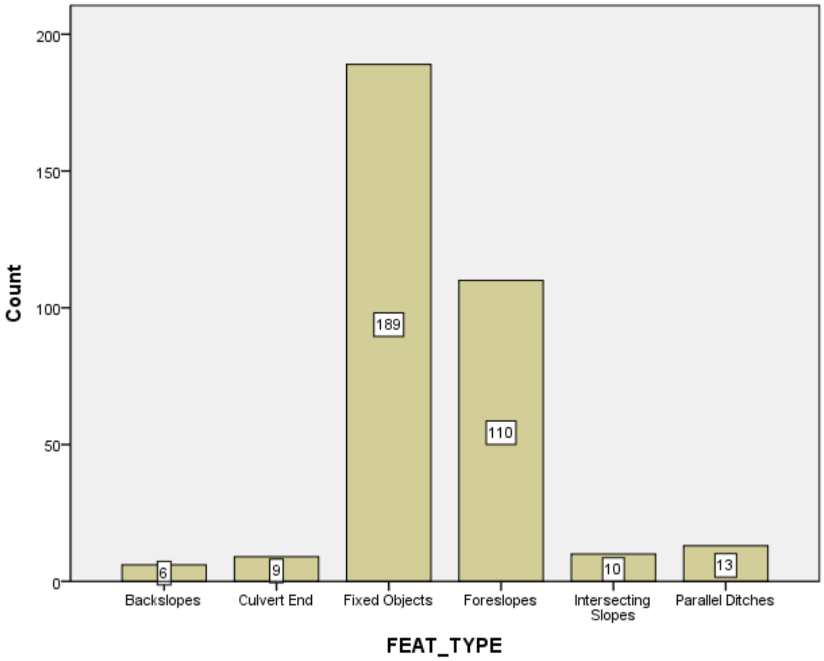

Figure 5.3: Number and classification of existing roadside features in the study

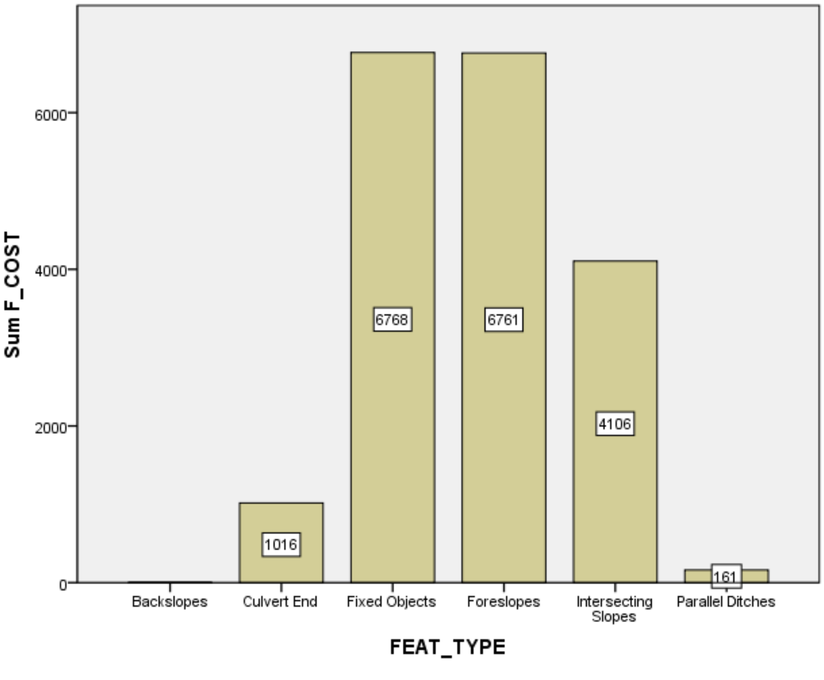

Figure 5.4: Cost distribution among existing roadside features in the study

5.4 Analysis of Foreslopes

The total annual crash cost for this study as computed by RSAP is $18,814. Of this amount, 35.9% is attributable to the presence of forslopes while they account for roughly a third (32.6%) of the existing roadside features. However, not all foreslopes are equal. From a safety point of view, foreslopes are classified as traversable (i.e., safe) and non-traversable. This classification is based on its measured slope perpendicular to the road centerline. It is considered that a slope 4 to 1 (a decrease of one foot in height for every four feet of width) is the steepest that can be considered traversable.

This engineering design criterion seems to be validated by the RSAP model. There are 110 foreslope features in the database. Eighty nine of them are traversable including 71 that are classified as flat ground. The remaining 21 non-traversable foreslopes account for 97.3% of the crash cost estimated by RSAP for the foreslope features.

From a modeling point of view, it would be expected that the crash cost of these feature could be related to its steepness and to its nearness to the travelled way. Moreover, it would be expected that the presence of the feature in relation to the length of the segment as well as the size of the feature (as measured by its area) would also be significant factors. Additionally, it would be expected that traffic (ADT) and speed could have explanatory power.

Table 5.3 presents the results of a linear regression model that includes these variables for all the foreslopes in the study to predict the estimated crash cost for each individual foreslope feature.

Table 5.3: Regression of feature cost on selected variables for all foreslopes

Variable	**Coefficient**	**t-value**	**Significance**
Off-set distance	-3.623	-0.755	0.452
Coverage in length	-1.603	-0.019	0.985
Area of the feature	0.037	2.350	0.021
Speed	7.232	2.240	0.027
Traffic volume	-0.004	-0.878	0.382
Constant	-197.084		
N	110		
R^2 (adjusted)	0.047		
Standard error of estimate	2.067		
Significance (p-value)	0.075		

There are several problems with this model. In the first place, we cannot reject the null hypothesis that all coefficients are zero at the 5% significance level. Consistent with this, its explanatory power is almost zero which means that we might as well use the average value of crash cost for all the foreslopes ($61.47) than considering this model. On top of this, the sign of the coverage and traffic are not intuitive.

When this same model was applied to only the non-traversable foreslopes, the results improved quite significantly. These are presented in Table 5.4. Firstly, the model explanatory power now is 46.8% and the first three variables are significant at a 5% (and even greater) level of significance. We can now reject the null hypothesis that all of the model's coefficients are zero. We can also see that the coefficients for speed and ADT are not significant. So in the next step we evaluate the model without these two variables. The results are presented in Table 5.5.

Table 5.4: Regression of feature cost on selected variables for non-traversable foreslopes

Variable	Coefficient	t-value	Significance
Off-set distance	-137.142	-2.705	0.016
Coverage in length	-1972.190	-2.624	0.019
Area of the feature	0.389	3.430	0.004
Speed	-15.536	-1.010	0.328
Traffic volume	0.002	0.068	0.947
Constant	2151.371		
N	21		
R^2 (adjusted)	0.468		
Standard error of estimate	4.513		
Significance (p-value)	0.010		

Table 5.5: Regression of feature cost on a reduced set of selected variables for non-traversable foreslopes

Variable	Coefficient	t-value	Significance
Off-set distance	-108.493	-3.130	0.006
Coverage in length	-1501.096	-2.614	0.018
Area of the feature	0.338	4.321	0.000
Constant	1243.379		
N	21		
R^2 (adjusted)	0.497		
Standard error of estimate	7.592		
Significance (p-value)	0.002		

The resulting model presented in Table 5.5 is selected because it has greater explanatory power but also because it is a simpler model. All the coefficients are significant and the only remaining issue is the sign for the coverage variable. However, when this variable was eliminated the resulting model had an adjusted R-value of 0.334. Figure 5.5 presents the probability plot of the regression standardized residuals and Figure 5.6 shows its corresponding histogram for the selected model.

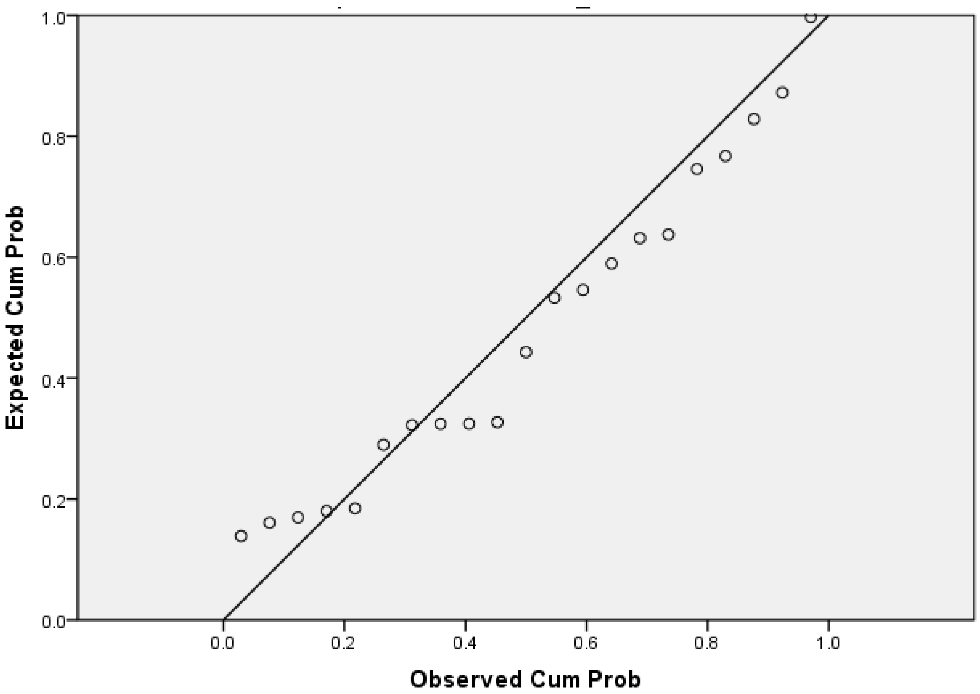

Figure 5.5: Probability plot for the regression standardized residuals for the model presented in Table 5.5

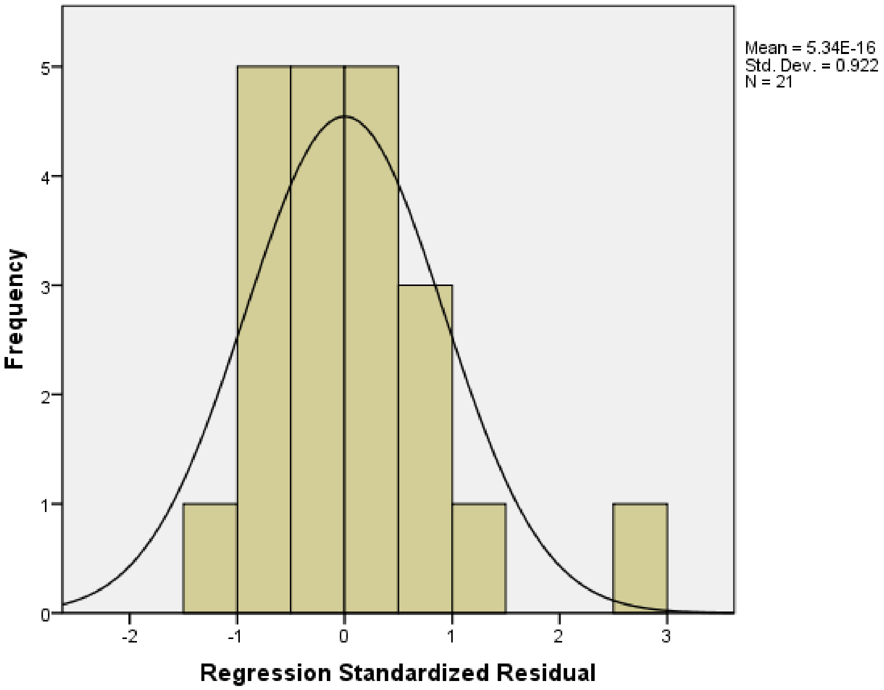

Figure 5.6: Histogram of the regression standardized residuals for the model presented in Table 5.5

5.5 Analysis of Intersecting Slopes

There are only 10 intersecting slopes (less than 3% of the total number of features) in this study but they account for 21.8% of the estimated crash cost computed by RSAP for all features. Its monetary contribution is $4106.05.

Unfortunately, there are not sufficient data points to conduct a thoroughly model development procedure with several explanatory variables. Table 5.6 presents the computed feature cost for each one of the 10 cases. It can be seen that slopes 2 to 1 or steeper having a drop of at least 3 feet make up for 96.4% of the crash cost attributable to intersecting slopes.

Table 5.6: Estimated crash costs for each intersecting slope feature in this study

Feature Unique ID	Feature Description	Feature Cost
7C1_6	2:1 (Negative), H = 1.0 m (3 ft)	$516.93
7C2_2	2:1 (Negative), H = 1.0 m (3 ft)	$1034.07
7C1_3	2:1 (Positive), H = 0.6 m (2 ft)	$0.00
18S2_3	2:1 (Positive), H = 0.6 m (2 ft)	$0.00
7C2_6	4:1 (Negative), H = 0.3 m (1 ft)	$115.93
10R_4	4:1 (Negative), H = 2.0 m (7 ft)	$0.00
7C2_4	4:1 (Positive), H = 0.6 m (2 ft)	$0.00
18S1_1	Vertical Drop, H = 0.3 m (1 ft)	$17.33
18S2_4	Vertical Drop, H = 0.3 m (1 ft)	$13.16
10R_5	Vertical Drop, H = 1.0 m (3 ft)	$2405.63

Under these conditions, a simple model with a dummy variable could be analyzed to see if the mean value of feature cost for these three cases is significantly different than the average value for all of them. This is equivalent to test the null hypothesis that the coefficient for this dummy variable is equal to zero.

Table 5.7 presents the results of this simple linear regression model. The t-value obtained for the dummy variable indicates that the corresponding coefficient is significant with a p-value of 0.005 for a two tailed test. Therefore, we can reject the null hypothesis that this coefficient is equal to zero.

We see that for these three segments having a feature with the characteristics indicated for the dummy variable to take the value of 1, the estimated average feature cost for intersecting slopes is $1319.88 while for the remaining 7 features the estimated feature cost is only $20.92.

Table 5.7: Regression of feature cost of intersecting slopes

Variable	Coefficient	t-value	Significance
Dummy = 1 if slope equal or steeper than 2 to 1, and drop equal or greater than 3 feet. Dummy = 0 otherwise	1298.96	3.851	0.005
Constant	20.917		
N	10		
R^2 (adjusted)	0.606		
Standard error of estimate	14.831		
Significance (p-value)	0.005		

5.6 Analysis of Fixed Objects

Fixed objects are the most prevailing roadside feature in this study. There are 189 fixed objects and together they account for 36.0% of the estimated total annual crash cost. However, similarly to what we learned about foreslopes, not all fixed objects are the same. There are five different types of fixed objects in RSAP: circular objects, rectangular objects, trees, wooden utility poles and breakaway type of signs. All of them, except the first one, were represented in this study.

Table 5.8 presents the number of the different types of fixed objects found and analyzed in this research. It also presents its contribution towards the estimated total annual crash costs computed by RSAP for the existing fixed objects.

Table 5.8: Summary statistics for cost of fixed objects features

Feature	Number of Cases	Feature Cost ($)				
		Sub-total	Mean	Standard Deviation	Min.	Max.
Breakaway Support, ΔV = 5 ft/s	40	4.38	0.11	0.042	0.00	1.05
Rectangle, W = 1.5 ft, H = 6 in.	8	9.76	1.22	0.775	0.00	6.53
Rectangle, W = 1.5 ft, H = 1 ft	1	321.80	321.80	n.a.	321.80	321.80
Rectangle, W = 1.5 ft, H = 1.5 ft	1	161.76	161.76	n.a.	161.76	161.76
Rectangle, W = 1.5 ft, H > 3 ft	36	3556.58	98.79	45.997	0.06	1372.51
Tree, 50 mm (2 in.) Dia.	5	0.35	0.07	0.044	0.00	0.21
Tree, 100 mm (4 in.) Dia.	12	8.40	0.70	0.700	0.00	8.40
Tree, 150 mm (6 in.) Dia.	4	4.97	1.24	1.104	0.05	4.55
Tree, 200 mm (8 in.) Dia.	6	21.17	3.53	1.859	0.08	11.69
Tree, 250 mm (10 in.) Dia.	6	41.38	6.90	3.260	0.00	20.19
Tree, 300 mm (12 in.) Dia.	4	72.59	18.15	16.233	0.24	66.71
Tree, >300 mm (12 in.) Dia.	37	1015.62	27.45	8.795	0.02	245.66
Wooden Utility Pole, 8 in. Dia.	7	110.40	15.77	12.519	0.06	90.68
Wooden Utility Pole, 10 in. Dia.	19	759.03	39.95	20.401	0.14	319.30
Wooden Utility Pole, 12 in. Dia.	3	680.11	226.70	113.490	0.06	350.73
Total	189	6768.30	35.81	9.858	0.00	1372.51

Looking at the above table it becomes clear that although breakaway support features are the most common (21.2% of all fixed object features), they have very little influence in the expected total annual crash cost of all fixed objects. This is quite an expected result because these breakaway features are designed to minimize their impact on an errand vehicle that leaves the travelled way.

Another observation is that trees less than 8 inches in diameter have very little influence on the computed total cost.

5.6.1 Rectangles

There are 46 fixed objects classified as rectangles in the database. Table 5.9 presents the results of the linear regression analysis to estimate the feature cost based on its offset distance, size (area), coverage (ratio between the feature's length plus width divided by the segment length), speed and volume of traffic.

The major problem with that model is the lack of significance of the coefficient for the offset distance. Speed and traffic volume, again, are not significant either and the sign of the coefficient for traffic volume is counter-intuitive. Removing these last two variables (speed and traffic volume) improves the model but the significance of the offset coefficient is still bothersome.

When the original model definition of Table 5.9 was applied to the subset of rectangles with height of three feet or more (36 data points) the improvement was rather substantial. Most importantly, it became clear that speed and traffic volume were causing a multi-collinearity problem because they are highly correlated (in this sub-set) having a Pearson correlation coefficient of 0.92. The final model is presented in Table 5.10.

Table 5.9: Regression of feature cost on selected variables for rectangles

Variable	Coefficient	t-value	Significance
Off-set distance	-4.854	-1.631	0.111
Coverage in length	-386.086	-3.607	0.001
Area of the feature	4.749	8.100	0.000
Speed	3.981	0.945	0.350
Traffic volume	-0.001	-0.269	0.790
Constant	-7.870		
N	46		
R^2 (adjusted)	0.593		
Standard error of estimate	14.103		
Significance (p-value)	0.000		

Table 5.10: Regression of feature cost on selected variables for fixed objects (rectangles having a height of 3 feet or more)

Variable	Coefficient	t-value	Significance
Off-set distance	-12.575	-4.219	0.000
Coverage in length	-372.128	-3.877	0.001
Area of the feature	5.164	10.660	0.000
Speed	12.783	3.082	0.004
Constant	-128.885		
N	36		
R^2 (adjusted)	0.793		
Standard error of estimate	34.518		
Significance (p-value)	0.000		

Table 5.10 presents the final model which is applicable when the fixed object feature is a rectangle having a height is 3 feet or more. Figure 5.7 presents the probability plot of the regression standardized residuals and Figure 5.8 shows its corresponding histogram for the selected model.

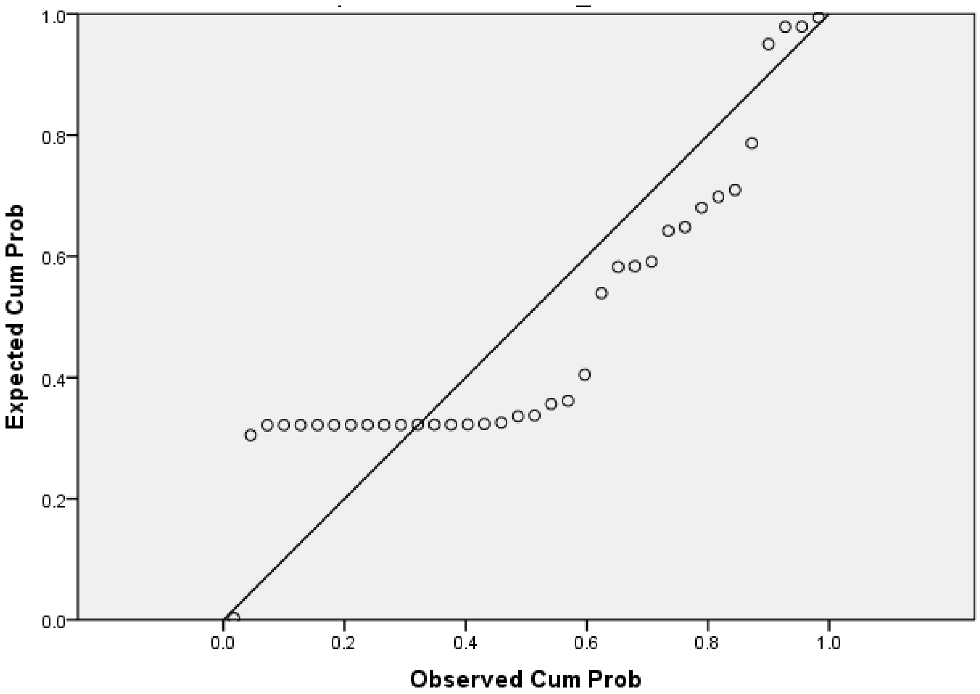

Figure 5.7: Probability plot for the regression standardized residuals for the model presented in Table 5.10

5.6.2 Trees and Utility Poles

At first it was thought that combining all trees and utility poles having a diameter equal or greater than 8 inches would yield a good model to predict the expected annual crash cost of these features taking together. However, the models obtained had very little explanatory power and the coefficients were not significant.

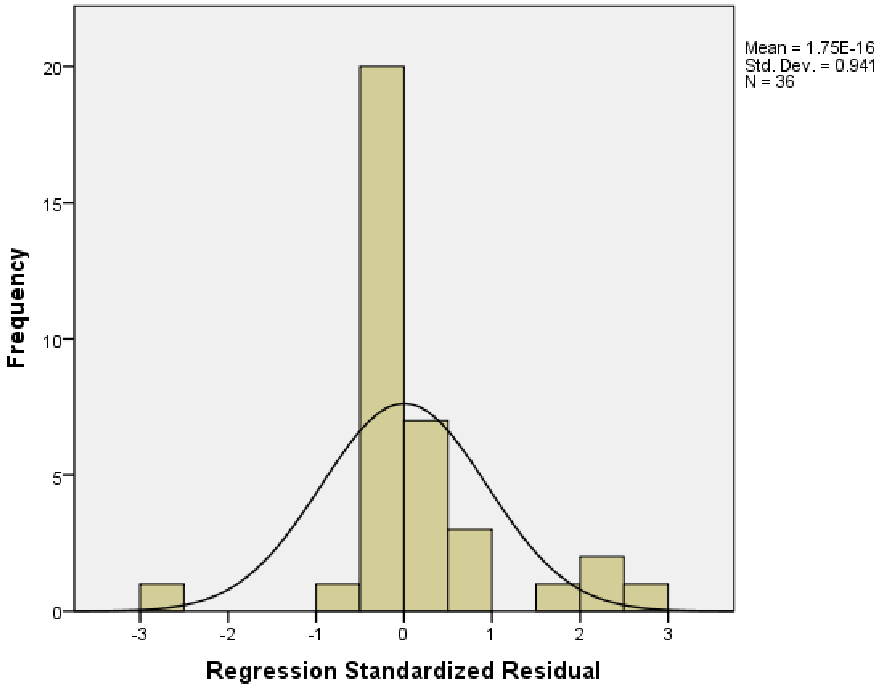

Figure 5.8: Histogram of the regression standardized residuals for the model presented in Table 5.10

The results improved somewhat when the wooden utility poles (29 data points) were analyzed independently. Table 5.11 presents the final model developed for wooden utility poles. Figure 5.9 presents the probability plot of the regression standardized residuals and Figure 5.10 shows its corresponding histogram for the selected model.

As per trees, several models were studied but all of them had an explanatory power of about 33% and with a coefficient for the offset variable not much significant. Since there were 74 data points for trees, several subsets were studied. The most relevant model was obtained for large trees meaning trees with a diameter of more than 12 inches. There were 37 such cases and the resulting model is presented in Table 5.12. Figures 5.11

and 5.12 present, respectively, the probability plot of the regression standardized residuals and its corresponding histogram for this model.

Table 5.11: Regression of feature cost on selected variables for fixed objects (wooden utility poles)

Variable	Coefficient	t-value	Significance
Off-set distance	-5.815	-2.365	0.026
Coverage in length	-5352.713	-2.840	0.009
Area of the feature	338.341	2.863	0.009
Speed	3.971	2.643	0.014
Constant	-156.596		
N	29		
R^2 (adjusted)	0.471		
Standard error of estimate	7.241		
Significance (p-value)	0.001		

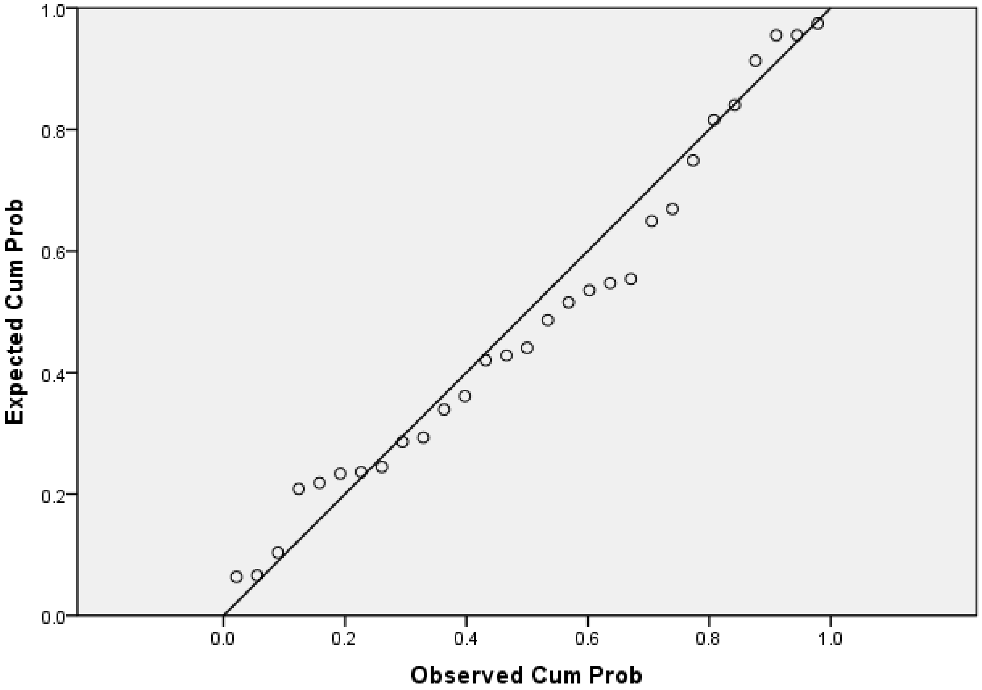

Figure 5.9: Probability plot for the regression standardized residuals for the model presented in Table 5.11

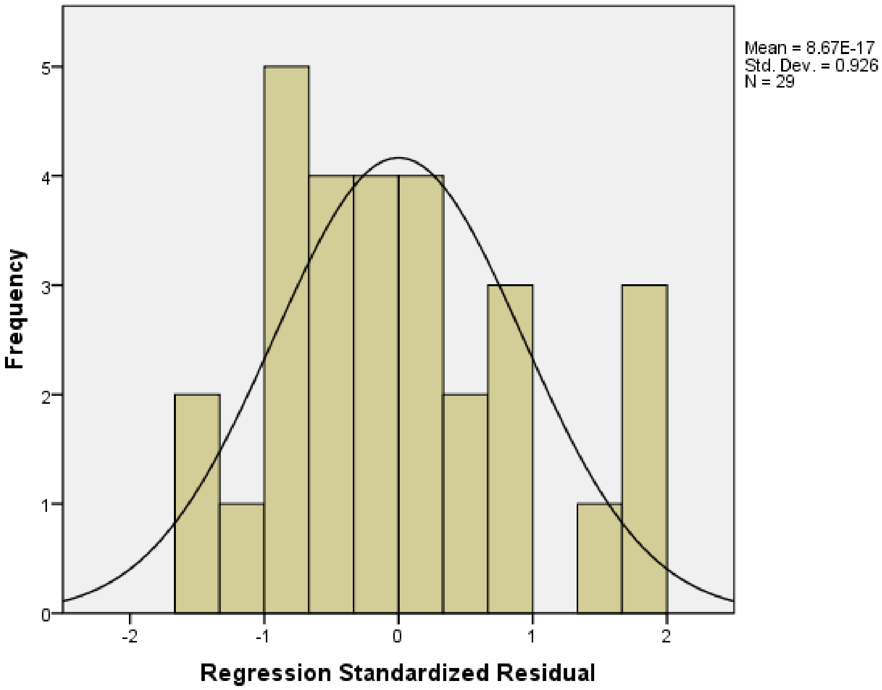

Figure 5.10: Histogram of the regression standardized residuals for the model presented in Table 5.11

Table 5.12: Regression of feature cost on selected variables for fixed objects (large trees with a diameter greater than 12 in)

Variable	Coefficient	t-value	Significance
Off-set distance	-2.014	-2.082	0.045
Coverage in length	-933.733	-1.801	0.081
Speed	4.610	5.431	0.000
Constant	-41.173		
N	37		
R^2 (adjusted)	0.586		
Standard error of estimate	18.008		
Significance (p-value)	0.000		

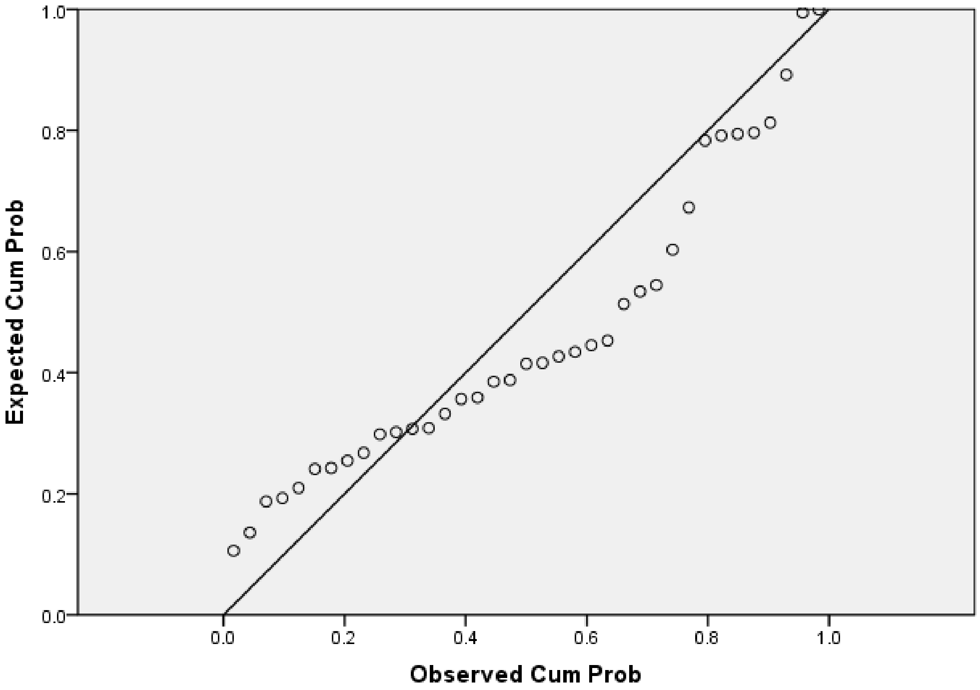

Figure 5.11: Probability plot for the regression standardized residuals for the model presented in Table 5.12

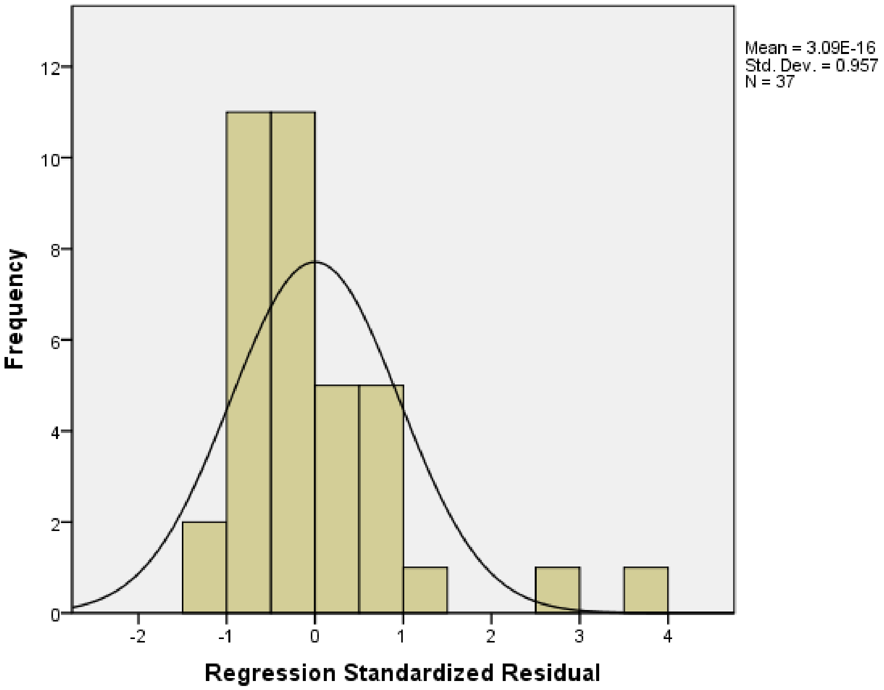

Figure 5.12: Histogram of the regression standardized residuals for the model presented in Table 5.12

As for the remaining 37 trees having diameters of 12 inches or smaller, their total combined contribution to the estimated annual crash cost is $148.86 which is only a 14.7% of the amount corresponding to large trees of diameter greater than 12 inches. Several models were studied but the greatest explanatory power obtained was 24.0% and for a very simple model with the speed as the only explanatory variable. All other variables considered had coefficients that were not statistically significant. This simple model is presented in Table 5.13. Figures 5.13 and 5.14 present, respectively, the probability plot of the regression standardized residuals and its corresponding histogram for this model.

Table 5.13: Regression of feature cost on selected variables for fixed objects (trees with a diameter of 12 in or less)

Variable	Coefficient	t-value	Significance
Speed	0.681	3.517	0.001
Constant	-11.152		
N	37		
R^2 (adjusted)	0.240		
Standard error of estimate	12.366		
Significance (p-value)	0.001		

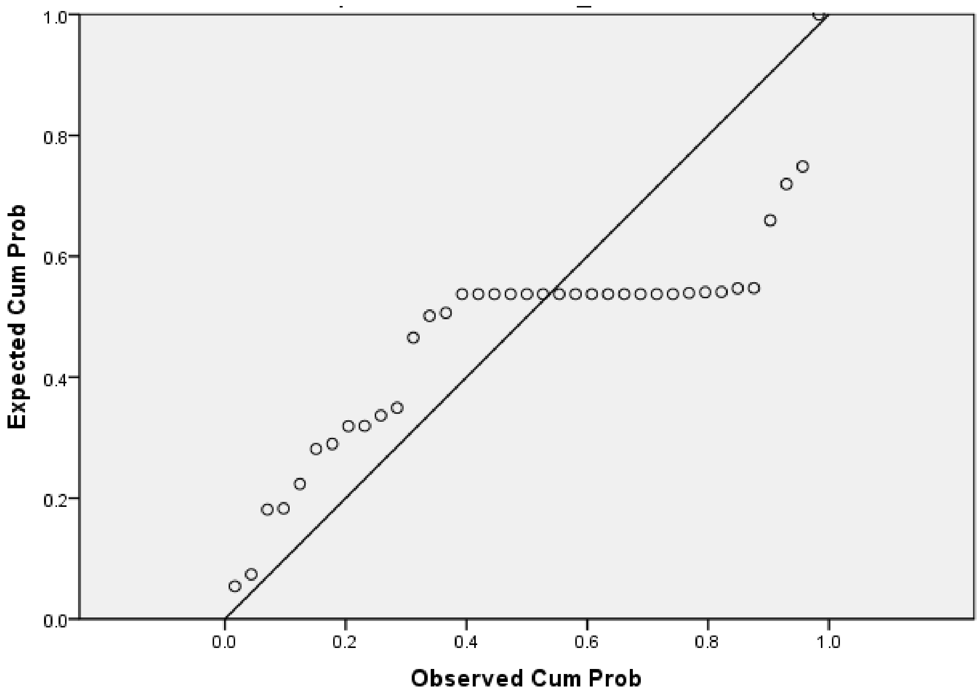

Figure 5.13: Probability plot for the regression standardized residuals for the model presented in Table 5.13

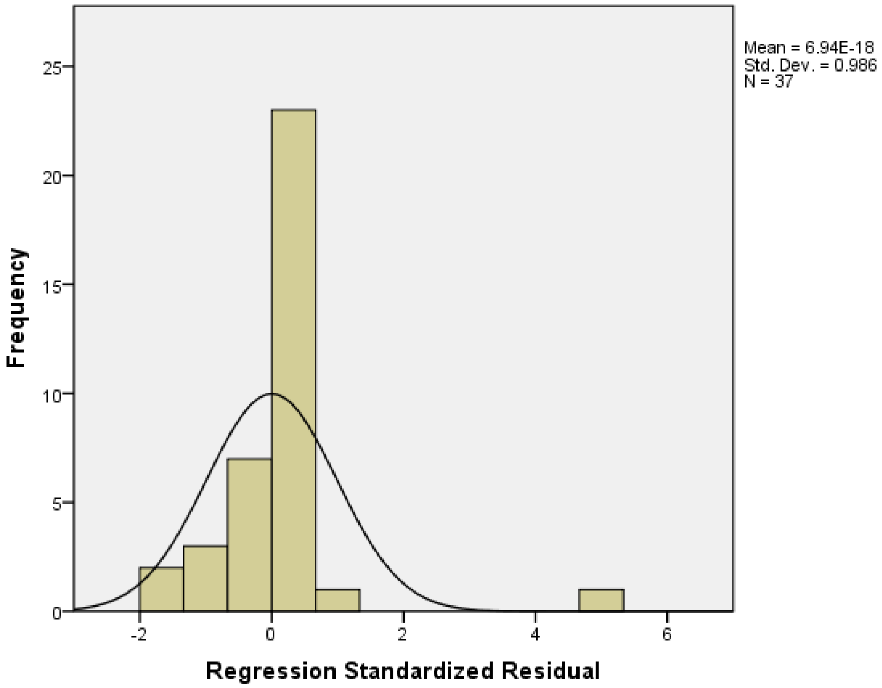

Figure 5.14: Histogram of the regression standardized residuals for the model presented in Table 5.13

5.7 Analysis of Culvert Ends

Similar to what was described for intersecting slopes, there are only 9 culvert ends in the database. This number is about 2.7% of the total number of features in this study. However, culvert ends account for only 5.4% of the estimated crash cost computed by RSAP for all features. Its monetary contribution is $1016.38.

No meaningful explanation could be found for the variation of the estimated annual crash cost on these features. The value computed by RSAP varies from $9.14 to $257.20. The average value of $112.93 will be used as the best estimate when a culvert end is present.

5.8 Comparing Results: Model Estimates vs. RSAP Computations

The models developed in the previous sections were used to estimate the annual feature crash cost (for each type of feature analyzed) based on their explanatory significant variables. For each one of the 337 features there are now two values for its annual crash cost: the one computed by the RSAP and the one estimated based on the models developed from the existing roadside environment.

Figure 5.15 presents the scatter plot of these two values along with the fitted line. It can be seen that the coefficient of determination (R^2) is 0.6953 which is rather good.

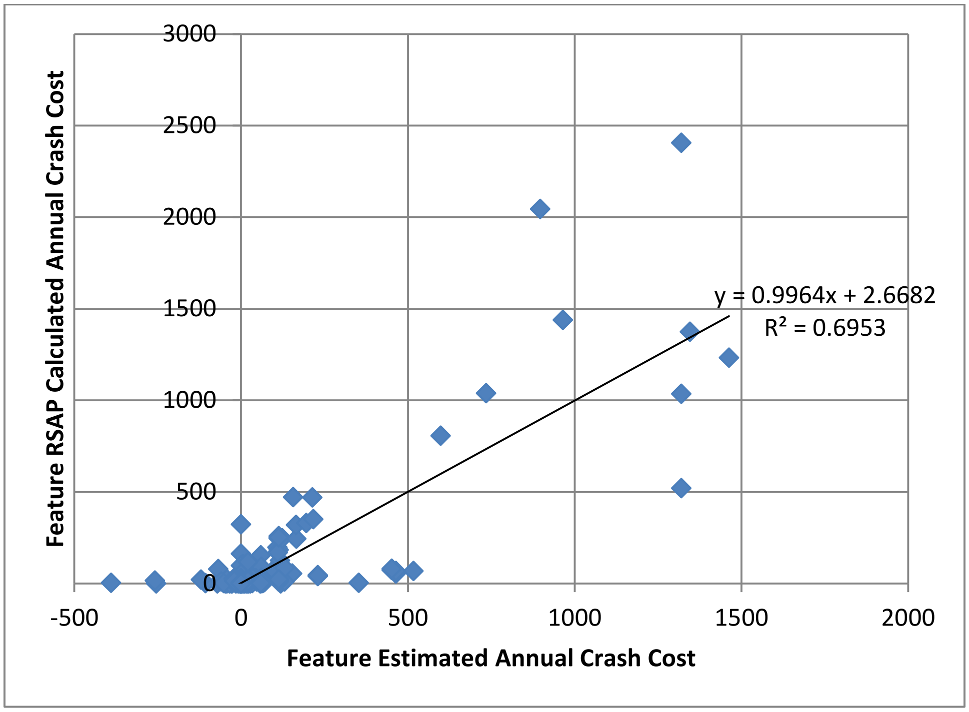

Figure 5.15: Scatter plot of the estimated annual crash cost vs. RSAP calculated values for each feature (N=337)

5.9 Comparing Results at the Segment Level

The previous section indicates that the methodology followed to develop the models to predict the annual crash cost for each feature provides a reasonable agreement with the values computed by the RSAP model. However, from a practical point of view there is a comparison of greater interest: that of individual road segments.

The annual crash cost at the segment level is computed as the addition of the costs associated with each feature existing in its roadside environment that might cause an accident once a vehicle leaves the travelled way. The expected value is computed by RSAP in its simulation routines. The estimated value is obtained from the models developed in this research. Figure 5.16 presents the scatter plot and the fitting line.

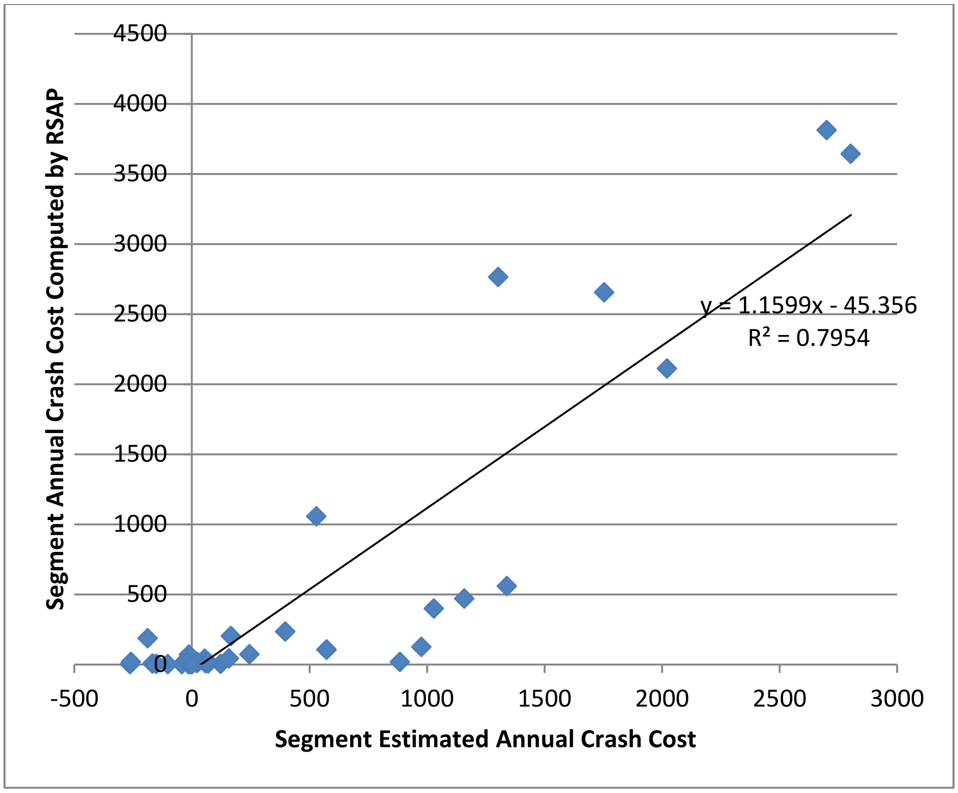

Figure 5.16: Scatter plot of the estimated annual crash cost vs. RSAP calculated values for each segment (N=45)

There are a total of 45 data points. As expected, the results at the aggregated level (segments) have a better coefficient of determination (R^2=0.7954) with the corresponding RSAP results. At this point, it might be argued that although the negative values estimated by our model are valid at the feature level but that the corresponding segment annual crash cost should be constrained to positive values only. If this restriction is imposed on the aggregated negative values obtained at any one segment, the coefficient of determination (R^2) improves to 0.8107.

5.10 Comparing Results at the Site Level of the Original Project

There is one final comparison that needs to be made. If we were to apply the regression models obtained in this chapter to the same 19 sites of the original project for Hillsborough County, would the ranking of the sites be the same as shown in Figure 3.1?

Table 5.14 presents the results. For each site, the risk index calculated in 2005 is compared with the value computed by RSAP as the sum of all the segments that make up the site. At the same time, the risk index found from adding the estimates obtained through the models is presented. Remember that the risk index as defined in the project for Hillsborough County is equal to the Annual Crash Cost of the site divide by $3,125 which is the value assigned to an injury level PDO2 (Property Damage Only, Level 2).

The same results are presented graphically in Figure 5.17. Here we can concentrate in the right hand side of the graph which shows the sites that should be selected as candidates for a detailed engineering study, namely Sites 10, 7, 8 and 2 according to the RSAP model in the original project.

Table 5.14: Comparing the Risk Index results

Site	Originally Computed Risk Index by RSAP	New Risk Index Computed by RSAP	New Risk Index Estimated with Regression Models
1	0.1	0.1	0.1
2	2.1	2.1	1.3
3	0.6	0.3	0.2
4	0.0	0.0	-0.1
5	0.0	0.0	-0.1
6	0.2	0.0	0.4
7	2.0	0.9	1.1
8	2.2	0.9	0.6
9	0.2	0.1	0.0
10	1.2	1.2	0.9
11	0.2	0.1	-0.1
12	0.1	0.0	0.0
13	0.0	0.0	0.1
14	0.3	0.3	0.7
15	0.1	0.1	0.4
16	0.0	0.0	-0.1
17	0.0	0.0	0.0
18	0.1	0.0	0.0
19	0.1	0.0	0.4

In general there seems to be good agreement. At least Sites 10, 7 and 2 would be chosen regardless of the approach used to arrive at its risk index. Site 8 seems to have the most troublesome results. Figure 5.17 shows that it could be left out and replaced by Site 14 if we were using the estimation based on the models developed in this dissertation.

At the same time, both the computed and the estimated risk index based on this research quite underestimated the value computed by the RSAP model in the original project. Something quite similar could be said about Site 7 and maybe about Site 3 as well.

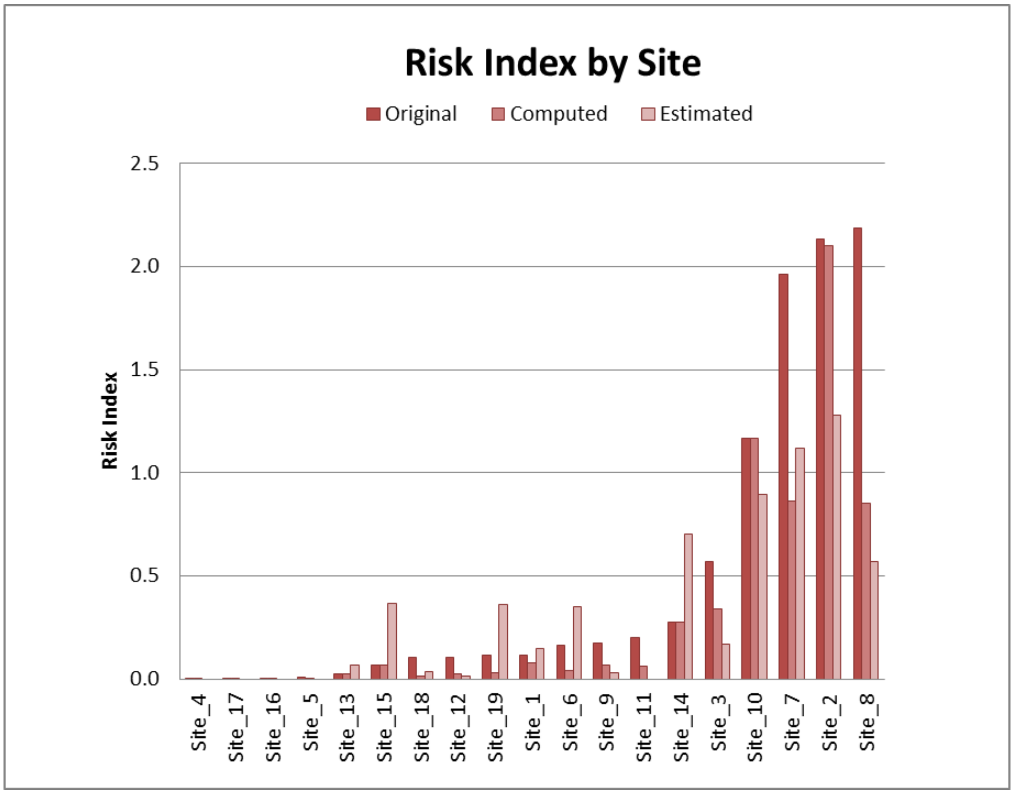

Figure 5.17: Comparing the Risk Index results

It would be worth investigating if the presence of a curve in those three sites might offer some explanation. One might imagine a vehicle encroaching at the end of a curve and hitting an obstacle located in the tangent segment that follows. When that same tangent segment is analyzed independently from the curve, the described event would not occur.

5.11 References

1. *Roadside Safety Analysis Program (RSAP), Version 2.0.3.* Developed under the sponsorship of NCHRP Project 22-9. 2001.

2. *Adobe Acrobat Pro X*. Version 10.1.1. Adobe Systems Incorporated. 2011.

3. *Microsoft Excel 2010, Version 14.0.6112.5000*. Part of Microsoft Office Professional Plus 2010. Microsoft Corporation. 2010.

4. *IBM SPSS Statistics*, *Version 19*. Release 19.0.0. SPSS Inc. 2010.

5. Delgado, I., J. J. Lu, and J. C. Pernía. *Methodology to Assess the Risk of Run-Off-Road Accidents in Hillsborough County Road Network*. University of South Florida, Department of Civil and Environmental Engineering, Transportation Program. Report presented to the Engineering Division, Public Works Department, Hillsborough County. Florida. 2005.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

In the United States, traffic fatalities have averaged almost 42,000 people every year during the decade 1994–2003. About 7% of these fatalities take place on the roads and highways of Florida.

Nationwide, on average, about one third of these fatalities occurs in run-off-road type of accidents. Collisions with trees are the most harmful event in more than a quarter of the accidents, while culvert (and ditches), embankments, guardrails and utility poles take 10% each.

Roadside environment is quite heterogeneous. And dangerous! The most desirable condition would be to keep all the vehicles on the road, to prevent them from running off the traveled way. However, there are many factors interacting on the observed reality, and consequently, actions need to be taken to reduce the severity of the crashes in the event of a vehicle running off the pavement edge.

6.1.1 Original Project for Hillsborough County

The results summarized in this report built upon a research study sponsored by Hillsborough County. The original study began as a search for a methodology to prioritize the installation of guardrails in the County’s road network (*1*). It started in December 2003 and it was completed in January 2005. Its main objective was to prioritize a total of 19 sites included in a list prepared by the County. The existing conditions in each site clearly showed that for many of them, guardrail might not turn out to be the most desirable solution. Consequently, the desired methodology was aimed to assess the risk of run-off-road type of accidents in each location.

In that study, a literature review and a survey of current practices were conducted to identify existing methodologies that could accomplish the stated objective. From the information obtained, it was decided that RSAP was the ideal tool. An acronym for “Roadside Safety Analysis Program”, RSAP was a newly available methodology with its own user friendly computer program. The model is built as a Monte Carlo simulation tool the implements the encroachment probabilistic approach to arrive at annual crash cost figures for a given road segment and roadside environment.

Most of the effort on that original project was aimed at collecting the required data needed by RSAP. Most of the initial office data was provided by several units within Hillsborough County. GIS techniques were extensively applied to obtain support data before going to the field. Field data collection was carried out with as few people as possible to master the fundamentals in order to achieve higher productivity per person, and most importantly, to reduce the risk associated with exposure to traffic especially in the sections with higher traffic volumes.

Another major effort was data reduction. The data collected had to be prepared for input into RSAP. This task was not as difficult because the personnel involved in collecting data had a good understanding of the data input requirements of RSAP. The analysis ran very smoothly. The analysis was concentrated on evaluating the existing conditions and in assessing the risk imposed by the roadside environment to the motorists on the road.

The results were summarized as the average annual crash cost to society in each location. Those sites having the highest values were the ones having the highest risk. Consequently, this same number was used as a ranking factor to prioritize the given list. The results clearly indicate that not all the sites deserve the same level of attention.

6.1.2 New Approach Developed for this Research

Based on the experienced and first-hand knowledge developed in the original project, RSAP's methodology continued to be used for the research presented in this dissertation. The objective here was to generate prediction model based on statistical regression analysis that could be used to estimate the annual crash cost calculated by RSAP. These values could then be added together at the segment level. The results obtained, as presented in Chapter 5, were quite satisfactory. The models developed are summarized in Table 6.1.

When the predicted results of these models were compared with the values calculated by RSAP for each feature, the comparison had a coefficient of determination (R^2) of 0.70. When the predicted costs of all the features in a segment were compared with the value calculated by RSAP for the same segment, the comparison fared even better with a coefficient of determination (R^2) of 0.80.

As it will be discussed next, these results are useful but their general applicability has to be carefully assessed. But certainly, the results are promising!

Table 6.1: Summary of regression models to predict annual crash cost by feature type

Variable	**Non-Traversable Foreslopes**	**Intersecting Slopes**	**Rectangles Height > 3**	**Wooden Utility Poles**	**Large Trees Diameter > 12”**	**Other Trees Diameter ≤ 12”**
Off-set distance	-108.493	n.a.	-12.575	-5.815	-2.014	n.a.
Coverage in length	-1501.096	n.a.	-372.128	-5352.713	-933.733	n.a.
Area of the feature	0.338	n.a.	5.164	338.341	n.a.	n.a.
Speed	n.a.	n.a.	12.783	3.971	4.610	0.681
“Dummy” (1 for drop>3ft,	n.a.	1298.96	n.a.	n.a.	n.a.	n.a.
Constant	1243.379	20.917	-128.885	-156.596	-41.173	-11.152
N	21	10	36	29	37	37
R^2 (adjusted)	0.497	0.606	0.793	0.471	0.586	0.240

6.1.3 Usefulness of the Results Obtained

Once they have been validated, the models obtained in this research can be used for a quick estimate of the potential annual crash cost of every link in a road network. The estimates for each link can be orderly ranked to determine which links exhibits the greater risk to the road users. The sites of higher risk can be studied at the project level using RSAP.

Alternative solutions according to the existing conditions of the roadside environment can be designed at each location. For each alternative, a cost estimate can be developed and the roadside conditions of the “as built” solution must be specified. This information would be used in RSAP to define alternatives. RSAP software would be used for the evaluation of each project (site) as compared with the do-nothing alternative (existing conditions) to obtain comparative costs and benefits to finally compute the corresponding benefit cost ratio for each alternative.

The sites would then be ranked based on their economic results assuring that the available funds would be used in locations deemed with the highest risk and that the solutions considered at each would be the most cost effective. Finally, this procedure would ensure that the order of execution would yield the highest economic return to society.

6.2 Conclusions

The objective of the original study was to establish a methodology to prioritize a list of candidate sites that were relevant to Hillsborough County officials in terms of roadside safety. Although all of these sites were included in the list for one or more valid reasons, the results obtained in the original research project clearly indicate that not all the sites deserve the same level of attention (*1*).

Three of these sites possess such risk indexes as to deserve immediate attention to mitigate the effects of the potential crashes predicted by the model. There were other sites that also deserved some attention but the urgency was not as pressing. Also, and of the same importance, more than half of the sections did not have a risk index that warranted any effort under the then existing conditions of roadside environment and traffic levels.

In this dissertation we have built upon the results and data obtained in the original project. Time allowed for a higher analytical effort with finer level of detail to conduct the analysis using very homogeneous segments. The unit of analysis became each roadside safety hazard. With this approach, it became feasible to develop statistically significant linear regression models to estimate what RSAP calculates.

6.2.1 On the Models Obtained

These models need to be validated in a separate study. However, because RSAP2012 is soon to be released, it would make more sense to wait for this new version of RSAP before going into validation. The database developed in this research can be used to replicate the analysis conducted here using the new version of RSAP.

Validation is required because no control sites were used in the development of the models. All of the original 19 sites (and therefore the 45 segments used in the research for this dissertation) were selected because they were deemed as dangerous sites in terms of run-off-road accidents.

There is also a need to have more study sites to cover the “mid area” of the annual crash cost at the segment level. See Figure 5.16. The same could be said at the feature level as indicated in Figure 5.15.

6.2.2 Important Highlights of the Models Obtained

One of the most significant results of this research is that reasonable approximations to the values computed by RSAP can be obtained with fewer data input requirements than those asked for in the model. This means that more sites can be included (for a general analysis of many sites) with a given level of resources and for the same amount of time.

The critical data would be that needed for the models obtained as presented in Chapter 5. It might even be possible to develop new procedures for data collection that could yield the variables needed with less effort.

Of course, such a conclusion can only implemented after the models developed have sustained evaluation and validation procedures ideally conducted by other independent research efforts.

This is especially true because one surprising result obtained was that not all variables that one would expect to have a significant contribution were present in the final models. For example, off-set was not significant in the estimation of crash cost for trees 12 inches or less in diameter. Speed was not significant in the crash cost estimates of non-traversable foreslopes.

The simple model developed for intersecting slopes was just a quick trick to capture such an important contribution (more than 20%) in the total annual crash cost.

6.2.3 Limitations of the Models Obtained

Although the results obtained with the models developed in this research are rather satisfactory, it was felt that a somewhat greater modeling effort could yield even better models. As previously stated, this additional effort might be better used after RSAP2012 is available to the public so more up-to-date research can be conducted.

As anticipated in the methodology in Chapter 3, an issue with the models developed was the interaction between explanatory variables for a given roadside safety hazard (like off-set and speed for example in explaining the annual crash cost of wooden utility light poles). No interaction terms were found to be statistically significant.

Of a more complex nature was modeling of the interaction between roadside hazards for a given segment, like trees near the travel lane located on a non-traversable slope. It was outside the scope of this research to model such type of interactions among the dependent variables of models treated as independent.

As for explanatory variables, it was expected that some variables could have a non-linear contribution to the prediction models. In particular, we tried to include a variable with an exponent different from 1.0 for the off-set values but the resulting coefficient was not statistically significant different from zero.

The spatial location of the roadside safety hazards deserves an additional consideration because there might be some degree of spatial dependency in our study subjects. This would lead to spatial autocorrelation and therefore to a violation of one of the basic assumptions in the basic statistical techniques used in our regression modeling, the independence among observations. This consideration was not studied at all in this research but it should not be overlooked totally in future research.

The lack of control sites is another drawback that should be addressed in future research.

6.3 Recommendations

The most important contribution of this dissertation is to indicate that it might be possible to use abbreviated procedures to estimate the expected annual crash cost of run-off-road type of accidents as a proxy of the risk to the road users. This “shortcut” method would allow to screen an entire rural road network and to search for those sites deemed “more dangerous”.

The database developed in this research would be a starting point for future analysis and validation studies. In this sense the first recommendation is that this research be repeated once the RSAP2012 becomes available. Then the issues indicated in the previous section could be addressed.

The new results, once validated, should be considered as the basis to establish a set of variables that could serve as predictors for the expected level of risk at a given roadway segment.

Results obtained with these new models for a complete rural road networks could be used as input data for accident rates in models such as the “Highway Development and Management, HDM-4” (currently featuring its Version 2.08) which is widely used in many countries (*2*).

The data collection efforts (for future research) described in Chapter 4 can be improved enormously with the use of appropriate technology. For example, total stations can be deployed to aid in all location and distance measurements. Alternatively, high tech solutions can be implemented through the use of LIDAR (Light Detection and Ranging) to generate point-cloud data that can be post-processed by computers to extract all elements of the roadway and of the roadside environment and export to road design and analysis software.

An intermediate approach that can be implemented at reasonable costs is the use of video to capture the existing condition of the roadway and the roadside environment. The video logs can be analyzed at the office to obtain the basic data needed for the analysis. Distances and cross slopes of the roadside can be measured using approximate techniques through marks on the screen or the video itself.

6.4 References

1. Delgado, I., J. J. Lu, and J. C. Pernía. *Methodology to Assess the Risk of Run-Off-Road Accidents in Hillsborough County Road Network*. University of South Florida, Department of Civil and Environmental Engineering, Transportation Program. Report presented to the Engineering Division, Public Works Department, Hillsborough County. Florida. 2005.

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ABOUT THE AUTHOR

Isidro Delgado was born in San José, Costa Rica and earned a Licentiate in Civil Engineering Degree from the University of Costa Rica and a Graduate Diploma in Statistical Techniques for Research from the “José Simeón Cañas” Central American University of El Salvador. He also earned a Master of Civil Engineering, a Graduate Certificate in Geographic Information Systems and a Ph.D. from the University of South Florida. He also attended the University of California at Berkeley as an International Road Federation Fellow.

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