Systematic Identification of High Crash Locations

Final Report

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SYSTEMATIC IDENTIFICATION OF HIGH CRASH LOCATIONS

FINAL REPORT

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EXECUTIVE SUMMARY

Background and Objective

Federal and state policy makers increasingly emphasize the need to reduce highway crash rates. This emphasis is demonstrated in Iowa's recently released draft *Iowa Strategic Highway Safety Plan* and by the U.S. Department of Transportation's placement of "improved transportation safety" at the top of its list of strategic goals. Thus, finding improved methods to enhance highway safety has become a top priority at highway agencies.

The objective of this project is to develop tools and procedures by which Iowa engineers can identify potentially hazardous roadway locations and designs, and to demonstrate the utility of these tools by developing candidate lists of high crash locations in the State. An initial task, building an integrated database to facilitate the tools and procedures, is an important product, in and of itself. Accordingly, the Iowa Department of Transportation (Iowa DOT) Geographic Information Management System (GIMS) and Geographic Information System Accident Analysis and Location System (GIS-ALAS) databases were integrated with available digital imagery. (The GIMS database contains roadway characteristics, e.g., lane width, surface and shoulder type, and traffic volume, for all public roadways. GIS-ALAS records include data, e.g., vehicles, drivers, roadway conditions, and the crash severity, for crashes occurring on public roadways during then past 10 years.)

Procedure

Using the GIMS and GIS-ALAS databases, high crash locations and relationships between crash rates and selected roadway design characteristics were identified. Based on input from county, state and consulting engineers, the project studied five crash types: (1) crashes on horizontal curves, (2) fixed-object crashes, (3) rural four-lane expressway intersection crashes, (4) head-on crashes (due to crossing the centerline), and (5) urban four-lane undivided corridor crashes.

Procedures were developed to integrate crash records and roadway characteristics (e.g., traffic volumes, number of lanes) to estimate the crash rate on any segment of the Iowa roadway network and rank high crash locations using the Iowa DOT's conventional procedure. (At the time of this study, the Iowa DOT ranked high crash locations by frequency, rate and loss. The three rankings were averaged to provide a final list of high crash locations.) Using the integrated database, statistical relationships between crash rates and roadway characteristics were then established. The resulting statistical models identify significant roadway geometric factors in causation of certain crashes.

In this project, geographic information system (GIS) based procedures were developed to facilitate the identification and analysis of elusive roadway criteria, e.g., curve radii, which are not identified by crash records. A method was also developed for determining the most recent daily entering vehicles at intersections and for reviewing and defining extents of location specific analysis (e.g., corridors).

A key deliverable of this research is the development of a combined automated and manual approach to identify curves. The strategy involved the application of a closed form solution to resolving curve radii and degree of curvature based on GIS-measured chord measurement (determination of curve radii from chord and length measurement typically involves a time-consuming iterative solution, which makes systematic analysis in a database difficult and time consuming).

Following a literature review to identify models relating crash rates and roadway characteristics, analysis of head-on and fixed-object crash data was conducted using a two-step process. First, descriptive statistics were obtained and comparisons were conducted for crash rates on different types of facilities (interstate, US highway, etc.). Second, regression models were estimated for head-on and fixed-object crash rates on different facilities to relate the crash rate to segment attributes (e.g., number of lanes, pavement type, and speed limit). A regression analysis was also conducted to explain the relationship of curve length and radius to crash rate in Iowa.

Results

As expected, results indicate that head-on crash rates are higher on lower classification (e.g., local and farm to market) highways. Rates are also affected by speed limit, terrain, shoulder width, shoulder type, and the pavement condition (international roughness index). For example, the results show that US and Iowa highways with higher speed limits have a lower head-on crash rate. While for a given facility, higher speed may result in more serious crashes, the finding is consistent as high speed limit roads are typically designed to a higher geometric standard. The models also indicate that crash rates decrease with increasing values of total shoulder width (i.e., the sum of inside and outside shoulder widths).

Also as would be expected, the analysis indicates that fixed-object crash rates are higher on lower classification (local and farm-to-market) highways. Terrain, type of pavement, shoulder type, the absence of median barriers, surface width, and number of lanes all tend to affect fixed-object crash rates on different types of highways. Not expected was the observation that, for interstate highways, highway segments in flat and rolling terrain tend to have higher crash rates compared to segments in hilly terrain. Similarly, segments with asphalt cement concrete pavement surface tend to experience higher crash rates compared to other types of surfaces. Moreover, segments with paved shoulders have lower fixed-object crash rates, where as segments with no median barrier tend to have higher fixed-object crash rates. Many of these observations are correlated with overall design standards, and, probably due to the rare and complex causal nature of crashes, few of the relationships have strong statistical significance. Table ES.1 summarizes the statistically significant roadway geometric factors in causation of fix-object and head-on crashes at the 90 or 95 percent confidence level.

As was expected from previous studies, the analysis of curve-related crash data indicates that the degree of curvature has a direct impact on crash rates on horizontal curves. Furthermore, the model indicates that the crash rate on shorter curve lengths is significantly higher than the crash rate on longer curves. This is probably because sharp curves are usually shorter than mild curves (see Reinfurt et al., Analysis of Vehicle Operations on Horizontal Curves, *Transportation Research Record 1318*).

Conclusions and Recommendations

In Iowa, as in most states, highway engineering safety improvement programs are reactive. In other words, safety countermeasures are applied to the roadway only after high crash rates have been observed. The objective of this project was to quantify the impact of highway geometry and design features on crash rates, enabling agencies to proactively identify and mitigate *future* problem areas.

The application of GIS in this project has enabled the research team to identify and analyze roadway segments characterized by specific criteria that are not identified by conventional crash analysis. Along the way, methods were developed for solving intermediate problems that will also find utility at state DOTs (e.g., determining most recent daily entering vehicles at intersections and reviewing and defining extents or location specific analysis). Another useful product is an improved corridor analysis methodology.

The project produced the following items:

- curve database for Iowa, with radii and length attributes
- procedures for identifying high crash locations of five types
- statistical models of the relationship between geometric features and crash rates
- candidate lists (maps and tables) for improvement (Iowa top 30 lists) for five problem types

Table ES.1 Statistically Significant Roadway Geometric Crash Causal Factors

	Interstate		US Hwy		IA Hwy		Farm-to-Market		Local	
	90% Conf.	**95% Conf.**	**90% Conf.**	**95% Conf.**	**90% Conf.**	**95% Conf.**	**90% Conf.**	**95% Conf.**	**90% Conf.**	**95% Conf.**
Fixed-object		Flat terrain ACC pavement Paved shoulders Rolling terrain No barrier	No barrier Surface width		Flat terrain	Combination pavement	Earth/gravel shoulders	ACC pavement PCC pavement	Flat terrain	ACC pavement PCC pavement No of lanes Speed limit
Head-on			Flat terrain Total shoulder width	Speed limit		Speed limit Total shoulder width IRI	Total shoulder width Unpaved shoulders			

1 INTRODUCTION

Federal and state policy makers increasingly emphasize the need to reduce highway crash rates. This emphasis can be witnessed at the state level in Iowa's recently released draft *Iowa Strategic Highway Safety Plan* and at the federal level by the U.S. Department of Transportation's placement of "improved transportation safety" at the top of its list of strategic goals (*1, 2*). Thus, finding improved methods to enhance highway safety has become a top priority at highway agencies.

The purpose of the research project was to develop tools and procedures by which Iowa engineers can identify potentially hazardous roadway locations and designs. Through selected case studies and using a system of integrated geographically referenced databases, the project identified high crash locations and relationships between crash rates and roadway design characteristics.

This project engaged a variety of existing databases in geographically referenced environments. The Iowa crash records and the Iowa road base records were the principal databases used. Other data sources used included cartography files, aerial photos, and Roadware pavement management centerline data. These databases were integrated to focus on safety analysis and monitoring, resulting in a composite database in which the roadway characteristics leading to heightened crash rates could be determined.

An important feature of the research is that it interconnected databases that had not previously been used together systematically to create a rich environment for conducting safety analyses. However, it is important to note that compiling the data sets needed for this project was possible only because of previous investments by the Iowa Department of Transportation (Iowa DOT) in the development of multiple geographically referenced databases.

Furthermore, statistical analyses of crash data revealed the relationship between crash rates and roadway design features, geometry, or other characteristics (e.g., speed limit, annual average daily traffic [AADT], surface type and condition). The resulting statistical models determined the most significant factors in causation of specific crashes. The identified contributing factors or "problem" types led to the determination of "problem" areas throughout the state. The graphical representation of the process is shown in a data flow diagram in Figure 1. By identifying design features and/or characteristics that may lead to higher crash risk, it is hoped that engineers could use the results to proactively reduce such hazards in future roadway designs or eliminate them in existing roadways.

This report consists of five chapters and four appendices. Chapter 1 is this brief introduction to the research project. Chapter 2 reviews relevant articles and reports. The approached strategies are documented in Chapter 3. Chapter 4 includes identification and ranking of high crash locations and statistical models for the selected study topics, and Chapter 5 contains conclusions and recommendations. The appendices include the procedures for curve identification, assessment, and ranking procedures.

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                    │ Select Study Topics │
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┌────────────────┐  ┌─────────────────────┐  ┌───────────────────┐
│ Crash Records  │  │  Perform Queries    │  │ Iowa Base Records │
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┌──────────────────┐                          ┌─────────────────┐
│ Cartography Files│                          │ Digital Photos  │
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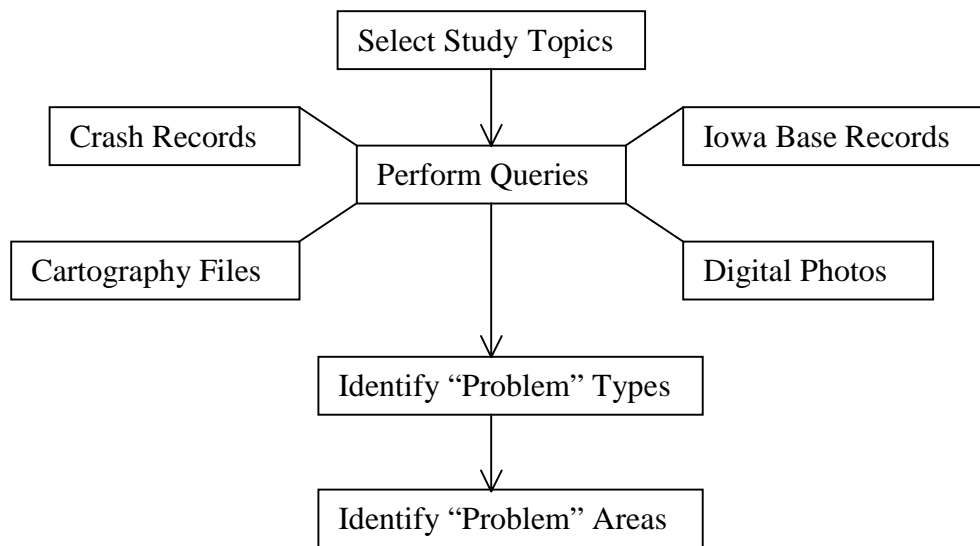
Figure 1 Data Flow Diagram

The project web site, located at http://www.ctre.iastate.edu/research/hcl/, has documented the project's activities. The information included at the web site ranges from minutes of project advisory committee and research staff meetings to illustrated, documented processes and methodologies.

2 LITERATURE REVIEW

Roadway characteristics have substantial impacts on traffic safety. In 1988, for example, fatality rates on rural interstate highways were reported to be less than fatality rates on rural federal and non-federal-aid primary arterials by factors of two and five, respectively (*3*). Potential factors that make crash rates different from one roadway class to another are physical roadway characteristics such as geometric design, markings, signs, and traffic conditions. Understanding the relative importance of design features to the safety of a facility can help engineers reduce or eliminate the use of certain unsafe features and incorporate other features that enhance safety. The literature review for this research focused on the geometric and environmental factors related to selected study topics.

2.1 Horizontal Curves

The crash rates on horizontal curves are 1.5 to 4 times higher than the crash rates on roadway tangents (*4*). The frequency and severity of these crashes, however, are the result of a large number of factors. These factors can include, but are not limited to, the radius, degree, and length of curve, superelvation, lane and shoulder widths, the type of curve transition, the preceding tangent length, and the vehicle speed reduction required. The literature review completed as part of this research project focused on the safety impacts of each of these factors.

The degree of a curve has an impact on the safety of the curve. One study found that crash rates increase as the degree of the curve increases, even when traffic-warning devices are used to warn motorists of the upcoming curve (*5*). Another study suggested that curves with curvature degrees of 15 or greater have a probability of 0.85 being hazardous (*6*). When the degree of curvature drops between 9 and 15 degrees, the probability of the curve being hazardous falls to 0.5. This probability is between zero and 0.27 for curves with curvature of less than nine degrees. When all vehicle types are being considered, a 1990 study suggests a maximum curve of 4.24 degrees (*7*).

The vehicle speed reduction required for traversing a curve has an impact on frequency and severity of crashes on curves. Abrupt changes in operating speed resulting from horizontal alignment are suggested to be a major cause of crashes on two-lane rural highways (*5*). Higher crash rates are experienced on horizontal curves that require greater speed reductions (*8*). This finding is also supported by the Fink and Krammes study (*9*), which indicates that curves requiring no speed reduction did not have significantly different mean crash rates from their preceding roadway tangents.

The roadway tangent lengths of a curve influence driver behavior. The effect of a long tangent preceding a curve becomes more of a factor on sharper curves (*9*). Roadway tangent lengths also impact crash rates of steep downgrade curves. Crash rates on a curve with long tangent lengths are more pronounced when the curve is located on a five-percent or more downgrade (*10*). The study found that highest crash rates occur on curves on steep downgrades with tangent lengths longer than 200 meters. The study further indicated that crash rates on isolated short radius curves can be reduced when the tangent lengths are about 150 meters or not located on very steep gradients.

There are conflicting view points on whether or not the presence of a spiral transition reduces crashes. A 1995 study suggested that spiral transition curves result in higher crash rates for downgrades and upgrades over four percent (*11*). No changes in crash rates were reported on the level terrain curves. On the other hand, in 1998, Council (*12*) found that the presence of a spiral curve could reduce crashes between two and nine percent. This range depends on the curve degree and its central angle. The average crash rate reduction experienced due to spiral transitions is estimated at five percent. When the spiral curve is on the level terrain, Council's model showed that the impact of spiral designs is more significant on sharper curves. The study further suggested that in mountainous areas, spiral curves should be used very seldom and only when the road has wide lanes and shoulders.

2.2   Fixed-Object Crashes

Many crash statistics have decreased during the 1990s, but the number of fixed-object crashes has continued to increase (*13*). Almost one-third of all roadway fatalities are the result of a single vehicle run-off-the-road crash, and many of these crashes most likely involved some type of fixed object (e.g., tree or ditch) (*14*).

In 1989, of the 6,644,000 crashes in the nation, 1,298,000 crashes, almost 20 percent, were involved in collisions with fixed objects (*15*). Fixed-object crashes in 1989 also accounted for almost 32 percent of the crashes involving severe or fatal injuries. Many factors are associated with the number of fixed-object crashes and their severity. These factors include the average daily traffic, the number of obstacles per mile, shoulder width, and object offset (*16*).

Utility poles and trees are the objects most frequently struck along urban and rural roadways, respectively (*14*). It was found that utility pole crashes accounted for about 20 percent of all objects struck in urban areas (*17*). This corresponds to over two percent of all crashes in urban areas. Utility pole crashes can result in severe injuries. More than 40 percent of utility pole collisions result in injuries, while about two percent are reported as fatal (*18*).

Furthermore, lateral clearance to the pole, traffic volume, and pole density are factors that are reported to affect utility pole crashes (*17, 18*). Other factors include time of day, travel speed, and road geometry. It was found that almost half of utility pole crashes happened after 8:00 PM, possibly due to driver fatigue or impairment, or low site visibility (*18*). The study concluded that utility poles located on curves were more likely to be involved in crashes than poles located on straight roadways.

As vehicle speed increases, the frequency of utility pole crash occurrences increases as well (*17*). This may be a result of a greater chance of vehicles running off the road at high speeds. A study of Greek rural roads found that 85 percent of the total crashes with fixed roadside objects were caused by loss of vehicle control and excessive speed (*19*).

Moreover, crashes with trees can be severe. Trees account for more single-vehicle, fixed-object fatalities than any other object along the roadway. Characteristic s of tree struck crashes are similar to crashes with utility poles. One study indicated that crashes with trees were more likely

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to occur in the early morning hours on Saturday or Sunday, possibly due to alcohol impairment (*20*). Traffic volume also affects crashes with trees. It was found that a majority of tree crashes occur during the late afternoon when higher traffic volume is observed. Similar to utility pole struck crashes, tree struck crashes on curves account for almost 60 percent of total tree crashes.

Lateral clearance also has an impact on severity and frequency of tree struck crashes (*20*). The study found that there was a four percent drop in tree crashes for every foot of clearance added from the edge of the pavement.

Lateral clearance is a major factor for all fixed-object crashes. It is desired to have a roadside that is relatively free of steep slopes and rigid objects so vehicles that do leave the roadway have a chance to recover before a crash occurs. When the roadside clear zone is flattened and increased, it is assumed a major reduction in fixed-object crashes will follow (*21*). Another study showed that almost 50 percent of all roadside obstacle crashes occurring with fixed objects had a lateral clearance of three meters or less (*19*).

Along with lateral clearance, lane and shoulder widths influence fixed-object crashes. Widening a lane can reduce fixed-object crashes by as much as 40 percent (*21*). With respect to fixed-object crashes, roadways with shoulder widths of less than seven feet are determined to be actually safer than the ones with wider shoulders (i.e., greater than seven feet) (*22*). This finding may be due to the fact that drivers perceive the roadway with wider shoulders safer, leading them to drive at higher speeds.

2.3   Head-on Crashes Due to Crossing Centerline

Head-on or cross-the-centerline crashes are relatively rare, but in 1998 they accounted for 16 percent of the highway fatalities in the United States (*23*). This type of crash is more frequent along urban highways, but more severe in rural areas. In fact, the possibility of a fatality occurring during a head-on collision is three times higher in rural areas (*24*). There are many roadway features that influence the probability of head-on collisions. Some of those features are pavement and shoulder widths, pavement conditions (e.g., wet or dry), alignment, roadside elements, and median width and type.

Both lane and shoulder widths affect the crash frequency of head-on collisions. Contrary to other crash types, the number of head-on collisions was found to be higher on narrow lanes (*25*). The most significant crash rate reduction occurs when widening eight-foot lanes to 11 feet wide. This improvement is believed to reduce both run-off-the-road and opposite direction crashes by as much as 36 percent.

The benefit of widening shoulders is not as clear as that of lane widening. It was found that head-on and run-off-the-road crash rates decrease as shoulder widths increase, up to the limit of nine feet (*25*). However, the study indicated a slight increase in crash rate for shoulders 10 to 12 feet wide. The widening of shoulders on both sides of the roadway from 1.6 to 8.2 feet could reduce run-off-the-road and opposite direction crashes by as much as 16 percent. The high amount of head-on crashes on roadways with narrow shoulders may be explained by the fact that narrow shoulders cause drivers to drive closer to the centerline of the road. Other studies have found that

shoulder widths had no significant effect on the frequency of head-on crashes, causing hesitation to accept the pronounced benefits of wider shoulders (*24*).

Medians are other roadway features that affect head-on crashes (*26*). The primary purpose of medians on divided highways is to provide an area for a vehicle that is out of control to recover. Medians need to be wide enough so that running-off-the-road vehicles can recover before entering the opposing lane causing a head-on collision.

Alignment of the roadway also affects the occurrence of head-on collisions. For example, in Japan, it was found that five percent of all crashes were head-on collisions (*24*). The crash rate for this type of crash increased as the horizontal radius decreased. Also, in England, an increase of head-on collisions was associated with an increase in the degree of a curve. The most significant increase of head-on crashes was reported on curves with over 3.5 degrees of curvature.

Two other factors impacting head-on collisions are vehicle speed and no-passing zones (*24*). Speed affects both the severity and the frequency of head-on collisions. Most fatal head-on crashes take place on roadways with high posted speed limits. It was found in Kentucky that 25 percent of the head-on collisions occur in no-passing zones. Another factor that increases head-on collisions is wet roadways (*27*). Both on urban and rural roads, an increase in head-on collisions is observed during rain.

2.4   Intersections Along Rural Four-Lane Expressways

Research projects that focus on crash relationships at the intersection of two-lane and four-lane divided rural roadways are still being investigated. However, some of the factors that influence crash rates at rural intersections are known to include time period, traffic volumes and movements, traffic control, geometry, environment (e.g., urban or rural), shoulder and median width and type, lighting, number of intersection approaches, and sight distance (*28*).

Shoulder types at rural intersections affect crash rates on high volume roads. It is suggested that paving shoulders at high volume rural intersections reduces the crash rate (*29*). Volume is another key factor in intersection crashes. Intersections with an average daily traffic of 8,000 vehicles are reported to observe 30 percent more crashes than lower volume intersections. However, traffic volume has no impact on intersection crashes on two-lane roads with shoulders compared with those of other roadway types.

The study found that installing lights at an intersection can reduce the average night crashes by as much as 52 percent (*30*). Traffic volumes also affect intersection crashes at lighted intersections. It was found that lighting an intersection with an average daily traffic above 3,500 vehicles significantly reduced the number of night crashes. Lighting an intersection also reduced crash rates at intersections that included either lane channelization or four legs.

The type of traffic control device used at an intersection affects the crash rate. Whether to use STOP or YIELD signs at intersections could be a challenging task. More fatalities and serious

injuries may be experienced if a YIELD sign is installed on a rural high-speed intersection with a speed limit higher than 30 mph (*29*).

Installation of traffic signals is common for major intersections, but intersections with these signals installed can have 29 percent higher crash rates than non-signalized intersections (*31*). Traffic signals normally reduce the number of angle collisions, but at the same time they increase the number of rear-end collisions.

Another traffic control strategy that has an impact on intersection crashes is the installation of flashers and beacons atop signal poles to alert approaching vehicles (*32*). The installation of a flasher at a normal intersection is expected to reduce property-damage-only rates. Similarly, the installation of a beacon reduces both the frequency and the severity of crashes.

Two other factors that would affect intersection crashes are number of approaches and sight distance (*31*). A study reports that four-leg intersections can have up to four times as much crash frequencies as at similar T-type intersections.

The review of research relating traffic safety to highway geometry provides guidance regarding design features that have a significant safety impact. Further, earlier research also provides important insight into statistical approaches for modeling relationships between highway features and geometry and highway safety. This research project provided additional analysis of these relationships for Iowa-specific case studies and a process by which Iowa can provide engineering and safety specialists feedback on the safety performance of Iowa transportation facilities.

3 METHODOLOGY

The primary objective of this project was to develop an integrated database by which locations with high crash occurrences can be identified. The Iowa Department of Transportation's Geographic Information Management System (GIMS) and the Geographic Information System Accident Analysis and Location System (GIS-ALAS) databases were the primary sources of data for this project. The GIMS database contains roadway characteristics (e.g., lane width, surface and shoulder type, and traffic volume) for all public roadways. GIS-ALAS records include data on crashes occurring on public roadways during then past 10 years (i.e., 1989–1998). These data include vehicles, drivers, roadway conditions, and the severity of the crashes. Other data sources used in the research include ortho-rectified aerial photos and Roadware pavement management centerline data.

The research team established processes to integrate crash records, traffic volume data, and roadway lengths to estimate the crash rate on any segment of the Iowa roadway network. This chapter presents the overall approaches of crash location identifications for the five selected study topics. Step-by-step procedures for all study topics are included in the attached appendices.

Furthermore, using the integrated roadway and crash databases, statistical relationships between crash rates and roadway characteristics were established. The resulting statistical models determined the significant roadway geometric factors in causation of certain crash types. The employed statistical methods are described later in this chapter.

3.1 General Assumptions and Effects

All crash analyses are based on six basic assumptions. These assumptions, and their potential effects, follow.

1. Crash locations, with respect to GIMS roadway centerline, are accurate.
   - Improperly located crashes may be misattributed to the roadway network, resulting in inaccurate crash analyses. Specifically, these crashes may be included in analyses at an incorrect location and omitted from analyses at the actual location.
   - Crashes that do not fall along roadway centerline, because of existing placement techniques, may be omitted from crash analyses, particularly when spatial selection criteria are utilized, for example, selection of crashes within a given distance of GIMS centerline. This may result in inaccurate crash analyses.
   - Crashes that could not be located geographically will not be considered in spatial-based, crash analysis. Therefore, crashes are omitted from analysis, yielding potentially inaccurate results.
   - Crashes are located using a single-year snapshot of the roadway network. Crashes occurring prior to the snapshot date may be incorrectly assigned to a new/different alignment, yielding potentially inaccurate results.

2. Crash attributes (from GIS-ALAS) are consistent and accurate.
   - Interpretation and/or completeness of crash forms may lead to inconsistencies in crash reporting and recording; therefore, the results of queries for crashes possessing specific characteristics may be inaccurate.

3. The roadway network has remained unchanged over the analysis period.
   - Use of single-year traffic data (AADT) for the entire analysis period may under- or over-represent crash rates over the analysis period.
   - Crashes occurring prior to the existence of current roadway characteristics may be included in multiyear crash analysis based on the current state of the facility. For example, crashes occurring on a two-lane roadway may be assigned to the newly improved, four-lane roadway along the same (similar) alignment. As a result, crashes occurring prior to the existence of current roadway characteristics may be included in analyses based on the current state of the facility.
   - If a facility has changed significantly during the analysis period, it must be removed for ranking analysis or addressed individually. This is because the location possesses a shorter, limited history, which would in turn likely impact its overall ranking, specifically with respect to total loss and crash frequency. Therefore, these sites are typically included in analysis and later identified and reviewed.
   - [Note: The GIMS "br_surface" table may be used to identify if, and when, significant facility changes or improvements occurred during the analysis period. Year and type of surface work activity, such as widening, resurfacing, and original construction, are among its attributes.]

4. Roadway characteristics (from GIMS) are consistent and accurate.
   - The roadway characteristics currently represented may not accurately reflect field data; therefore, locations of certain roadway characteristics may not be accurate.

5. Road characteristic attributes in GIMS are more accurate than crash data.
   - Therefore, crash data will not be limited to those records satisfying the necessary roadway characteristics. Upon ranking, Iowa DOT personnel will review the highest-ranking sites. In the process, identifying and/or eliminating highly ranked locations experiencing improvements during the analysis period.

3.2 Identification of High Crash Locations

The project advisory committee was presented with 16 potential study topics (see Table 1), from which five were selected. These topics were (1) horizontal curves, (2) fixed-object crashes, (3) rural four-lane expressway intersections, (4) head-on crashes (due to crossing the centerline), and (5) urban four-lane undivided corridors. These topics were identified as being of potential immediate interest to local highway agencies and/or the Iowa DOT. In addition, it is useful to note that many of the remaining topics can readily be studied using the methodologies developed in this project.

Table 1 Potential Study Topics

Study Topic
Identify high accident locations occurring during wet weather conditions
Identify high run-off-the-road accident locations on paved as well as gravel roads
Identify high fixed-object accident locations on paved as well as gravel roads
Identify safety impact of elderly drivers
Identify high accident locations along urban 4-lane undivided roadways
Identify safety impact of horizontal curve characteristics (e.g., degree, radius)
Identify safety impact of speed limits of 50 mph or more on expressways
Identify safety impact of speed limit
Identify safety impact of traffic volume and traffic mixture
Identify safety impact of shoulder surface conditions (e.g., paved or unpaved)
Identify safety impact of the number of accesses per mile
Identify safety impact of pavement markings
Identify signalized intersections with high number of accidents
Identify safety impact of signalized turning bays
Identify stop-signed intersections with high number of accidents
Identify safety impact of turn lanes in creating traffic turbulence and weaving

3.2.1   Horizontal Curves

3.2.1.1   Scope
Statewide analysis was performed on primary roadways only. Secondary road analysis was performed for Story County, Iowa, only.

3.2.1.2   Assumptions, Constraints, and Potential Errors
- Statewide analysis was limited to crashes occurring on primary roadways (Interstate, US, or State) as defined by the "road type" field in GIS-ALAS. If the value of this field was not coded properly, an incorrect number of crashes were assigned to a site. For example, if a secondary roadway was mistakenly coded as an Iowa route, crashes occurring along this roadway, if within a given proximity of a curve, were assigned to the curve. On the other hand, if crashes along a primary road were coded as a local street, these crashes were omitted from consideration. Visual inspection of sites in question and manually assignment or removal of crashes may be required to correct this problem.

- Given that curve crashes may not fall exactly on the cartographic representation of the roadway centerline, crashes falling within a given proximity of the curve were assigned to the curve. In some instances, e.g., when another primary road intersects the curve, crashes along approaches of the intersecting roadway were automatically, and incorrectly, assigned to the curve. This results in an inaccurate representation of crash frequency, crash rate, and, presumably, loss along the curve. These locations may be corrected by limiting the extent of the intersecting roadway(s) included in the curve polygon.

- Crashes occurring at intersections along a curve were unrelated to the curve and not included in crash frequency, crash rate, and loss calculations, ultimately affecting final ranking. Curves at intersections may require independent visual inspection prior to the initial ranking or upon initial assessment of the ranking results.

- Potential "problem" curves have at least one crash indicated as occurring on a curve (in the "roadway geometric" field of GIS-ALAS) during the analysis period. Curves with less than three crashes during the 10-year analysis period do not constitute high crash locations. These assumptions narrow the analysis scope and limit the number of low traffic volume curves with high crash rates due to a single crash. However, since crash rate is potentially the only factor indicating possible problem areas on low volume roadways, these areas may not be included in site rankings.

- All crashes occurring along a curve but not denoted as such in GIS-ALAS were captured and included in analysis. This limits the impacts of possible variation in the field reporting of curve locations.

- All curves were circular. Furthermore, use of a single, well-defined curve identification methodology by trained personnel provides curve definitions within an accuracy level acceptable for determining approximate curve geometry. This includes identifying the transition between circular and spiral curves.

- Although a single, well-defined methodology for curve identification was utilized, errors in the manual identification of curves may still be present, e.g., excessive curve lengths and right-angle corners defined as a curve. As a result, these locations were ranked among correctly defined curves, yielding inaccurate results in ranking. These sites may be eliminated from consideration, or edited, through independent visual inspection prior to the initial ranking or upon initial assessment of the ranking results.

- GIMS representations of road centerline do not adequately represent curve alignment. Therefore, other data sets were used, where available, in curve identification and definition.

- GPS-based driven way centerline (with coordinate values presented at 100-meter increments) adequately represents curve alignment as do curve alignments heads-up digitized over aerial photography.

- A weighted-average value for the most recent AADT along the GIMS representation of a curve provides a reasonable estimate of average AADT for the analysis period. This simplifies crash rate determination, eliminating year-by-year analysis of individual curve segments possessing different traffic volumes. However, the resulting crash rates may not be entirely accurate for curves experiencing significant changes in traffic volume over time and/or along its length.

- Reverse curves and continuous curves were considered as a single curve in crash analysis because, in some cases, crash location did not readily indicate which curve influenced the crash. No curve geometric data were calculated for these locations.

- During a multiyear analysis period, the alignment of a roadway may change, e.g., construction of a bypass. If the original alignment was through a municipality, crashes prior to the realignment was coded as a primary route. If these crashes fall within a given proximity of a curve, they were automatically, and incorrectly, assigned to the curve. This results in an inaccurate representation of crash frequency, crash rate, and, presumably, loss along the curve. These locations may be corrected by defining the curve polygon more precisely, omitting the previous alignment.

3.2.1.3 Analysis Approach

The first step in identifying high crash location curves was determining the location of curves in general. GIMS segmentation does not break at curves and only indicates the number of curves that have posted advisory speed limit signs or whether a curve exists (all or in part) along a section (for limited, primary roads only). Therefore, systematic curve identification strategies were required to define individual curves and their extents.

Using GIMS, GIS-ALAS, aerial photos, and Roadware data, the research team incrementally developed and evaluated a number of horizontal curve identification strategies. Strategies were evaluated using a quantitative assessment (accuracy level) indicating total error as well as component measures of Type I and Type II error. Type I error is the percent of records that have been identified as curves but, through visual inspection, are determined to be tangent alignments. Type I error will result in non-curve (tangent) alignments being included in crash analysis, potentially yielding non-curve high crash locations. None-the-less, problem areas will be identified. Type II error, however, is more serious. Type II error is the percent of records that have been identified as a tangent alignment, while visual inspection indicates a curve. Problem areas, specifically high crash curves, will not be identified.

Complete descriptions of the incremental curve identification strategies, development costs, procedures, and accuracy assessments are included in Appendix B**.** The final, improved, identification methodology integrates many of the strategies discussed in Appendix B.

Potential curve locations were identified through two techniques. The first technique used crash records to identify potential curve locations (crash locations) where roadway geometry at the crash was noted as a curve. The second technique used the change in bearing between adjacent Roadware-based line segments (100 meters in length). Roadware-based centerline data were generated using information collected as part of the Iowa Pavement Management Program (IPMP). A program was developed to identify adjacent records and calculated the change in bearing between them. In general, a change of bearing of five degrees or greater indicated a change in alignment associated with a curve.

Locations satisfying the aforementioned criteria were then visually inspected. Approximate locations of points of curvature and tangency were defined by digitizing a polygon over the Roadware-based, centerline data, where available. These polygons were designed capture all proximate crashes as well as Iowa DOT roadway cartography. In areas where Roadware-based centerline was unavailable, curves were manually defined using heads-up digitizing over aerial

photographs. Polygons were also drawn around curves defined in this manner to capture proximate crashes and cartography.

Several spatial processing functions were applied to calculate curve and chord length, associate crashes to each curve, and extract traffic data from proximate cartography. Crash data were summarized for each curve, and the radii and degree of curvature calculated using the closed form solution. Using circular curve equations (Equations 1 and 2), Equation 3 is derived to define the relationship between the length and chord length of the curves. Equation 3 is a function of θ (i.e., half of the deflection); thus, it can be rearranged into Equation 4. Equation 4 and its derivative (Equation 5) are then plugged into the Newton iteration equation (Equation 6) to estimate θ. This, in turn, facilitates the calculation of the radius and degree of a curve (R and D) through the use of Equations 1 and 7, respectively.

$$L = 2R\theta \tag{1}$$

$$\frac{C}{2} = R\sin\theta; \text{ see triangle xyz} \tag{2}$$

$$\frac{C}{L} = \frac{\sin\theta}{\theta} \tag{3}$$

$$f(\theta_n) = \frac{\sin\theta_n}{\theta_n} - \frac{C}{L} \tag{4}$$

$$f'(\theta_n) = \frac{\cos\theta_n}{\theta_n} - \frac{\sin\theta_n}{\theta^2_n} \tag{5}$$

$$\theta_{n+1} = \theta_n - \frac{f(\theta_n)}{f'(\theta_n)}; \ n = 0, 1, 2, ... \tag{6}$$

$$D = \frac{5729.579}{R} \tag{7}$$

where

L = curve length
C = chord length
R = curve radius
D = curve degree
$\theta = \dfrac{\Delta}{2}$; Δ = deflection angle

As shown in Table 2, the values of θ's converge rather rapidly.

Table 2 Curve Geometry Closed Form Solution

C (ft)	L (ft)	θ (0)	θ (1)	θ (2)	θ (3)	θ (4)	θ (5)	θ (6)	R (ft)	D (deg)
949	963	1	0.52189	0.343226	0.29917	0.296007	0.29599	0.29599	1626.74	3.52
943	961	1	0.53581	0.371941	0.33786	0.336188	0.33618	0.33618	1429.28	4.01
416	427	1	0.55916	0.417759	0.3953	0.394685	0.39468	0.39468	540.94	10.59
780	790	1	0.51565	0.329986	0.28043	0.276148	0.27611	0.27611	1430.56	4.01
774	788	1	0.53261	0.365435	0.32931	0.327377	0.32737	0.32737	1203.53	4.76

The number of crashes, crash rate, and total loss (property damage and injury) were calculated for each curve and used to rank each location using the Iowa DOT's standard procedure. In addition, regression analyses (discussed later), were performed on curve geometry and crash rate to determine the existence (or strength) of a relationship.

3.2.2 Fixed-Object Crashes

3.2.2.1 Scope
Statewide analysis was performed on all levels of roadway (primary, secondary, and municipal).

3.2.2.2 Assumptions, Constraints, and Potential Errors
- Intersection crashes were not included in analysis. Therefore, resulting high crash locations do not include fixed-objects (e.g., stop signs) located at intersections.

- Locations with less than three fixed-object crashes, or crashes with a specific object type (e.g., utility pole) during the 10-year analysis period do not constitute high, fixed-object crash locations. This assumption narrows the analysis scope and limits the number of low traffic volume locations with high crash rates due to a single crash. However, since crash rate is potentially the only factor indicating possible problem areas on low volume roadways, these areas may not be included in site rankings.

- Given that crashes may not fall exactly on the GIMS representation of the centerline, crashes falling within a given proximity of the roadway, 20 meters for urban and 50 meters for rural, were assigned to the adjacent GIMS section. (These values represent the respective accuracies of GIMS cartography.) In some instances, crashes along parallel roadways or approaches of the intersecting roadway were automatically, and incorrectly, assigned to a

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GIMS section. In other instances, the spatial limits did not capture all appropriate crashes. Both result in an inaccurate representation of crash frequency, crash rate, and, presumably, loss along the GIMS section.

3.2.2.3 *Analysis Approach*
Statewide fixed-object crash locations were identified using the 1989–1998 crash data. An integrated database was developed including the number and type of fixed-object struck for each GIMS section. The inclusion of object type allows certain types of fixed-objects, such as ditches, guardrails, retaining walls and fences, to be eliminated from analysis, facilitating analysis on problem objects that can more easily be mitigated with lesser costs. The process for fixed-object crash determinations is included in Appendix D.

Creation of the integrated, fixed-object database required analysis of two different GIS-ALAS record sets, incident-related and vehicle-related records. Fixed-object crashes are incident-related, while struck objects (fixed-object) types are vehicle-related. The objective of the analysis was to identify all crashes in which a vehicle struck a fixed-object, even if the incident itself was not coded as a fixed-object collision. For example, an incident may be recorded as non-collision, but the vehicle record may indicate that a tree was struck. Therefore, the technique limits the omission of fixed-object crashes by not relying solely on incident-records.

The number of crashes, crash rate, and total loss (property damage and injury) were calculated for each GIMS section and used to rank each location using the Iowa DOT's standard procedure. These analyses were also performed for a specific type of fixed-object, utility poles, to demonstrate the versatility of the integrated fixed-object database.

Upon ranking, visual inspections were conducted to detect potential erroneous crash location assignments. The aforementioned analyses, and re-ranking, were performed as needed. The resulting rankings identify high crash locations based on GIMS segmentation. A future methodological enhancement is to perform a proximity analysis, based on crash location, to further narrow (refine) problem locations and/or identify specific, offending objects.

3.2.3   Rural Four-Lane Expressway Intersections

3.2.3.1 *Scope*
Statewide analysis was performed on primary roadways, as defined below.

3.2.3.2 *Assumptions, Constraints, and Potential Errors*
- Primary roadways satisfying the following criteria were identified for analysis: (1) non-Interstate, primary roadways, (2) comprised of four or more lanes, and (3) located outside incorporated areas. These criteria may yield non-expressway facilities, specifically four-lane facilities immediately adjacent to an incorporated area (extensions of urban four-lane roadways), and omit expressways located in rural portions of incorporated areas. GIMS attributes that may improve facility selection are speed limit, lane type (indicating through, left turn, right turn, etc.), urban area code (indicating an urban area, possibly unincorporated) and corporate line–city number (representing a roadway located on a corporate boundary).

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- Intersecting GIMS roadways were located within 16 meters of the four-lane facility of interest. This assumption was made to limit the number of sections identified for use in determining intersection entering traffic volumes.

- Rural intersection crashes met the following criteria: (1) recorded as rural, (2) possess a valid intersection identifier and intersection class, and (3) character of roadway is intersection. If the values of any of the pertinent attributes were not coded properly, an incorrect number of crashes were selected and included/omitted from analysis. This results in an inaccurate representation of crash frequency, crash rate, and, presumably, loss at the intersection.

- Rural four-lane expressway crashes were located within 50 meters (approximate cartographic accuracy) of selected GIMS centerline (expressway and intersecting roadways). Given that crashes may not fall exactly on the cartographic representation of the roadway centerline, intersection crashes not within this distance were not analyzed. This results in the possible omission of intersection as well as an inaccurate representation of crash frequency, crash rate, loss, and overall ranking. To identify possible omissions, selected intersections may require independent visual inspection prior to the initial ranking or upon initial assessment of the ranking results.

- Most recent AADT values serve as an acceptable estimate for daily entering vehicles (DEV) and crash rate calculations for the entire analysis period. This eliminates the need for year-by-year crash rate calculation, but depending on traffic patterns may under- or over-represent crash rates.

- Intersection geometry was unchanged during the analysis period. While not acknowledging intersection improvements, this assumption may over-represent crash history prior to an improvement. Selected intersections may require independent visual inspection prior to the initial ranking or upon initial assessment of the ranking results to identify intersections that were improved during the analysis period.

3.2.3.3   Analysis Approach

Statewide crashes at intersections along rural four-lane expressways were identified for a five-year analysis period (1994–1998). First, all four-lane, rural roadways were identified and selected, using attributes contained in the GIMS database. Next, all roadways within a specified proximity of these roadways were spatially identified and selected. This selection set represented the roadways intersecting, or immediately adjacent to, rural four-lane expressways. Crashes occurring at intersections were then identified from GIS-ALAS. Of these crashes, only those within a specified proximity of the rural four-lane roadways or intersecting roadways were selected. All values used in proximity analyses (spatial selections) were expected GIMS cartographic accuracy.

The selected locations were buffered to a distance approximately equal to the expected GIMS cartographic accuracy. All roadway segments intersecting this buffer were assigned the corresponding ALAS node number. After a unique ALAS node number was assigned to each roadway segment, the total daily entering traffic at each intersection was calculated. All crash data, including total number of crashes and total dollar loss (property damage and injury), were

also summarized for each intersection. Intersections were ranked using the Iowa DOT's standard procedure. The process for determination of crashes at rural expressway intersections is documented in Appendix D.

The primary benefit of this technique is that it may be repeated as necessary to account for changes in GIMS segmentation and record keeping practices. It is also applicable to all functional classes of roadways. Limitations are that not all GIMS sections terminate at intersections, and sections may be shared by multiple intersections. Therefore, without visual inspection or an automated identification technique, the intersection configuration may not be readily apparent, resulting in potential errors in traffic volume determination. Visual inspection was utilized in this analysis to ensure the validity of the aforementioned analyses.

3.2.4 Head-on Crashes Due to Crossing Centerline

3.2.4.1 Scope
Statewide analysis was performed on rural, two-lane paved roadways (primary and secondary).

3.2.4.2 Assumptions, Constraints, and Potential Errors
- Intersection crashes were not included in analysis. Therefore, resulting high crash locations do not include head-on crashes at intersections.

- A 10-year analysis period was used because of the infrequency of head-on crashes.

- Locations with less than three head-on crashes during the 10-year analysis period do not constitute high, head-on crash locations. This assumption narrows the analysis scope and limits the number of low traffic volume locations with high crash ra tes due to a single crash. However, since crash rate is potentially the only factor indicating possible problem areas on low volume roadways, these areas may not be included in site rankings.

- Given that crashes may not fall exactly on the GIMS representation of the centerline, crashes within a 50 meters of the roadway were assigned to the adjacent GIMS section. (This value represents the approximate accuracy of GIMS cartography.) In some instances, crashes along parallel roadways or approaches of the intersecting roadway were automatically, and incorrectly, assigned to a GIMS section. In other instances, the spatial limits did not capture all appropriate crashes. Both result in an inaccurate representation of crash frequency, crash rate, and, presumably, loss along the GIMS section.

3.2.4.3 Analysis Approach
Rural, two-lane paved roads were first selected from the GIMS database. Head-on crashes due to centerline crossing were then selected from GIS-ALAS for a 10-year analysis period (1989–1998). A 10-year analysis period was used because of the infrequency of this type of crash. Of these crashes, only those within 50 meters of the rural, two-lane paved roads were selected. These crashes were then assigned to the proximate GIMS section. The number of crashes, crash rate, and total loss (property damage and injury) were calculated for each GIMS section and used to rank each location using the Iowa DOT's standard procedure. The process for data integration and determination of high head-on crash locations is documented in Appendix D.

3.2.5 Urban Four-Lane Undivided Corridors

3.2.5.1 Scope
Statewide analysis was performed on primary roadways, as defined below.

3.2.5.2 Assumptions, Constraints, and Potential Errors
- Primary roadways satisfying the following criteria were identified for analysis: (1) non-Interstate, primary roadways, (2) comprised of four through lanes of traffic and no center bi-direction left turn lane, (3) possess no median, (4) located within an incorporated area, and (5) AADT is less than or equal to 14,000. This AADT constraint represents a threshold value above which four-lane to three-lane conversion would not be practical. Since traffic volumes and lane make-up may change at GIMS sections, the aforementioned criteria may yield discontinuous results. In addition, facilities of interest may extend beyond corporate limits. Visual inspection and/or use of the urban area code (indicating an urban area, possibly unincorporated) and corporate line-city number (representing a roadway located on a corporate boundary) may be useful in identifying these locations.

- Urban crashes met the following criteria: (1) recorded as urban or within a city and (2) located on a US or Iowa highway.

- Urban undivided four-lane crashes were located within 16 meters (cartographic accuracy) of GIMS centerline. In some instances, crashes along parallel roadways or approaches of the intersecting roadway were automatically, and incorrectly, assigned to a GIMS section. In other instances, the spatial limits did not capture all appropriate crashes. Both result in an inaccurate representation of crash frequency, crash rate, and, presumably, loss along the GIMS section.

- Intersection crashes were included in analysis, but traffic volumes from entering intersection legs were not. Therefore, resulting crash rates will be over-represented.

- Roadway geometry was unchanged during the analysis period. While not acknowledging design changes or improvements, this assumption may over-represent crash history prior to an improvement. Selected facilities may require independent visual inspection prior to the initial ranking or upon initial assessment of the ranking results to identify locations that were improved during the analysis period.

3.2.5.3 Analysis Approach
The primary objective of this analysis was to investigate the potential reduction to three-lanes or widening to five-lanes to reduce crash rates. First, all GIMS sections meeting the specified criteria, including specific lane configurations, were automatically assigned a corridor identification number, a concatenation of the county number, city number, and route number of the segment. These corridors were visually inspected and the corridor identifier adjusted, when necessary, to establish corridor continuity through an urban area and to the facility termini. Since traffic volumes and lane configurations may change along these corridors, visual inspection was

utilized to assign a second unique identifier to each roadway segment.[1] Partial corridors represented shorter, more homogeneous segments (e.g., possessing similar traffic volumes) along a corridor. In some cases, however, no significant change occurred along the corridor, and, as a result, it was not partitioned. Analysis of partial corridors may be useful in isolating problem areas along a corridor. Each corridor and partial corridor was comprised of multiple GIMS sections.

Both intersection and mainline crashes, occurring within a specified distance of these roadways from 1994–1998, were selected and assigned to the appropriate GIMS section. All crash data, including total number of crashes and total dollar loss (property damage and injury), were then summarized for each corridor and corridor segment.

Using the total length of a corridor (or corridor segment) in conjunction with individual GIMS traffic volumes and lengths, a weighted traffic volume for each corridor and corridor segment was calculated (see Equation 8).[2] Furthermore, crash rates for each corridor and partial corridor segments were calculated.

$$\text{weighted\_AADT} = \sum_{i=1}^{n} \frac{\text{segment}_i\_\text{length}}{\text{corridor\_length}} \times \text{segment}_i\_\text{AADT} \tag{8}$$

where, n is the total number of segments along a corridor.

Corridors, as a whole, were then ranked using the Iowa DOT's standard high crash location ranking procedure. Partial corridors (and homogeneous corridors) were also ranked using the Iowa DOT's standard procedure. The process for identification of four-lane undivided corridors and partial corridors with high crash occurrences is documented in Appendix D.

3.3 Causal Factors and Regression Analysis

Using the integrated databases for the head-on, fixed-object, and horizontal curve crash analyses, the impact of roadway characteristics on crash rates was investigated. Roadway characteristics of interest available through GIMS, as identified by several highway safety engineers, are presented in Table 3.

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[1] The visual inspection involved analyzing the cartographic representation of each roadway segment and its associated attributes. The technique currently used to place crash data within GIS does not necessarily place the crash directly on the roadway centerline. In addition, no explicit relationship between crashes and roadway centerline exists. Therefore, different techniques must be utilized to try to establish this relationship. Thus, the cartographic accuracy of the data must be taken into consideration. Through both spatial and attribute analysis, assigning crashes from adjacent roadways will be limited or eliminated.

[2] The most recent year's AADT was assumed to be the average AADT for the entire analysis period.

Table 3 Selected Roadway Characteristics

Characteristic	Description
System	Interstate US highway Iowa highway Farm-to-market road Local road
Type_section	Normal section One-way main direction of travel is northbound or eastbound One-way main direction of travel is southbound or westbound
Terrain	Flat Rolling Hilly
Median type	No barrier (< 0.152 m curb) Hard surface w/o barrier (raised Median) (PV) Grass surface w/o barrier (SL) Hard surface w barrier (PV-BR) Grass surface w barrier (SL-BR) Barrier (< 0.152 m curb) (Jersey barrier, center of road parking, etc.)
Median width	
Surface type	Primitive (no shoulder) Unimproved (no shoulder) Grade and drained earth w/o borrow topping (no shoulder) Combination surface—concrete and brick or block
Surface width	
Out shoulder type	No shoulder Earth Gravel Paved
Out shoulder width	
In shoulder type	No shoulder Earth Gravel Paved
In shoulder width	
IRI-tested	Yes/No
IRI	Recorded to the hundredth of a meter
Number of lanes	
Year counted	The year in which the traffic count was taken
AADT	
Speed limit	

3.3.1 Head-on Crashes Due to Crossing Centerline

First, descriptive statistics were obtained for head-on crash data, and comparisons were conducted for crash rates on different types of facilities (Interstate, US highway, etc.). This provided information on the relative safety of different types of facilities.

A statistical comparison was carried out to ascertain whether the mean head-on crash rates were different across different types of highway systems. Tukey's *t*-test was utilized to determine significance of differences in the mean head-on crash rates among different highway systems at the 95 percent confidence level. The null and the alternative hypotheses were as follows:

H_o: The mean crash rates are the same across the two highway systems.
H_a : The mean crash rates are different across the two highway systems.

The decision rules were as follows:

If $|t^*| \leq t$ (1-0.05/2; n-1), conclude H_o, i.e., crash rates are the same.
If $|t^*| > t$ (1-0.05/2; n-1), conclude H_a, i.e., crash rates are different across the two highways.

After determining that crash rates were different on various types of highways, the second step was to estimate linear regression models for head-on crash rates and isolate segment-related characteristics that affect them. Head-on crash rate on each type of highway segment was the dependent variable in regression, and segment related characteristics (e.g., speed limit, terrain, shoulder width, shoulder type, etc.) were the independent variables. Different independent variables were tried in each model specification to isolate the ones with statistically significant effects on head-on crash rates.

A measure of how well a regression model explains the variability in the dependent variable is the *R*-squared value, which can vary between zero and one. An *R*-squared value of zero would indicate that the regression model does not account for any variability in the dependent variable, where as a value of one would indicate perfect explanation of the variability. Thus, *R*-squared values closer to one indicate a better model, given that the independent variables in the model have been sensibly chosen (i.e., there should be some relevance between the dependent and independent variables).

The model formulation process involved repeated re-specification of the models by including and excluding the variables available to the researchers. As such, for each model a number of variables and their combinations were tested in the specification. Variables that showed some explanatory power were retained in the model specification, and the ones showing little or no explanatory power were excluded from the model specification. The reported models (see Chapter 4) are the best that the research team members could obtain from the data.

3.3.2   Fixed-Object Crashes

First, descriptive statistics were obtained for fixed-object crash data and comparisons were conducted for crash rates on different types of facilities (Interstate, US highway, etc.). This provided information on the relative safety of different types of facilities.

Statistical testing by means of Tukey's *t*-tests on differences in mean fixed-object crash rates across different types of highways followed similar null and alternative hypotheses as in head-on crashes.

Fixed-object crash rate models were estimated with several segment-related characteristics as independent variables. Although a single model for interstate and Iowa highways could have been estimated because of non-significant difference in the fixed-object crash rate, separate models for the two were estimated. The two types of highways differ in terms of geometric standards, traffic, and maintenance practices.

3.3.3   Horizontal Curves

Linear regression analyses were performed to determine whether crash rates are related to the curve length and degree of curvature. A total of 3,004 curves were identified throughout the state, among which 1,072 curves had no crash occurrences during the analysis period (1989–1998).

4 RESULTS

This chapter presents the top 30 high crash locations for each study topic. These results represent locations satisfying an initial quality assessment, with respect to crash assignment and/or facility designation, by the research team. Site review did not include an assessment of site-specific geometric changes or improvements during or after the analysis period. Roadway geometric characteristics were based simply on the GIMS data available at the time analyses were performed. Therefore, an urban facility recently converted from four-lane to three-lane may be included in the top 30 list of urban four-lane undivided roadways. Iowa DOT personnel familiar with the specified locations should make a final qualitative assessment of the high crash locations presented in this chapter.

This chapter also presents the results of the descriptive statistics and regression analyses performed for head-on, fixed-object, and horizontal curve crashes.

4.1 High Crash Locations

4.1.1 Horizontal Curves

The top 30 high crash, rural primary curves are presented in Table 4. Curve locations are presented in Table 5 and Figure 2. In addition, Figure 3 presents an example large-scale, site-specific map useful in precisely identifying curve location for field review.

Rankings for Story County secondary roads are presented in Table 6 and Figure 4. Very few curves (six of 28) on secondary roads in Story County had more than one crash in the 10-year analysis period; therefore, these locations may not actually constitute high crash locations. Given the previously defined assumptions, locations with fewer than three crashes in a 10-year analysis period would not have been included in ranking; however, because of the limited number of curves, all locations were included. Several of the crash rates are very high because of a single crash occurring on a low volume roadway.

Table 4 High Crash Locations—Rural Curves

Statewide Rank	Total Crashes	Freq. Rank	Crash Rate (MVM)	Rate Rank	Dollar Loss	Loss Rank
1	14	19	27.40	4	964,123	29
2	20	4	77.92	1	673,703	93
2	12	31	10.23	24	889,983	43
4	12	31	10.49	21	831,219	56
5	9	62	8.06	38	892,870	42
6	11	38	6.37	82	831,215	57
7	6	158	23.34	6	864,250	46
8	10	46	4.97	147	953,206	34
9	7	119	7.06	61	371,956	104
10	8	90	25.01	5	172,400	193
10	6	158	8.21	36	641,317	94
12	5	234	27.88	3	822,632	63
13	13	24	4.25	213	447,955	99
14	5	234	7.43	49	829,800	58
15	8	90	5.73	111	258,509	142
16	8	90	6.12	94	197,661	177
17	12	31	4.89	153	168,149	197
18	10	46	5.65	113	150,428	223
19	6	158	5.91	103	268,700	131
20	9	62	4.60	183	214,400	173
21	9	62	3.78	270	305,500	116
22	6	158	3.62	291	1,755,800	4
23	12	31	7.67	46	60,006	391
24	23	2	10.16	25	42,521	443
25	4	353	6.70	69	843,000	52
26	7	119	5.33	128	147,203	233
27	12	31	8.58	34	45,506	433
28	8	90	16.06	8	53,400	408
29	8	90	4.11	229	174,353	192
29	7	119	4.45	193	166,828	199

Table 5 High Crash Locations—Rural Curves (Descriptions)

Statewide Ranking	County	Route	Nearest Milepost	Offset (mile)
1	MILLS	US 275	39	-0.34
2	CLARKE	US 69	45	-0.05
2	JOHNSON	US 6	261	0.00
4	DES MOINES	IA 99	16	0.00
5	CALHOUN	US 20	88	0.22
6	ALLAMAKEE	IA 26	4	0.00
7	GUTHRIE	IA 925	17	-0.09
8	CRAWFORD	US 59	98	-0.06
9	DICKINSON	IA 276	2	0.00
10	CLARKE	US 69	47	0.00
10	IOWA	US 6	220	0.13
12	DICKINSON	IA 276	6	0.27
13	APPANOOSE	IA 2	175	0.00
14	WINNEBAGO	US 69	211	-0.25
15	LEE	IA 103	5	-0.07
16	DUBUQUE	US 52	58	0.02
17	CHEROKEE	IA 3	59	-0.05
18	MARION	IA 14	52	-0.09
19	ALLAMAKEE	IA 26	9	-0.17
20	MUSCATINE	IA 22	77	-0.23
21	DUBUQUE	US 52	38	-0.05
22	MILLS	IA 385	3	-0.39
23	CHEROKEE	IA 31	31	0.11
24	HAMILTON	IA 17	47	0.34
25	MONONA	IA 141	22	0.28
26	MARSHALL	IA 330	28	-0.24
27	POTTAWATTAMIE	IA 183	6	-0.34
28	MILLS	US 275	39	0.14
29	PLYMOUTH	IA 3	31	-0.45
29	ALLAMAKEE	IA 76	8	0.00

Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.
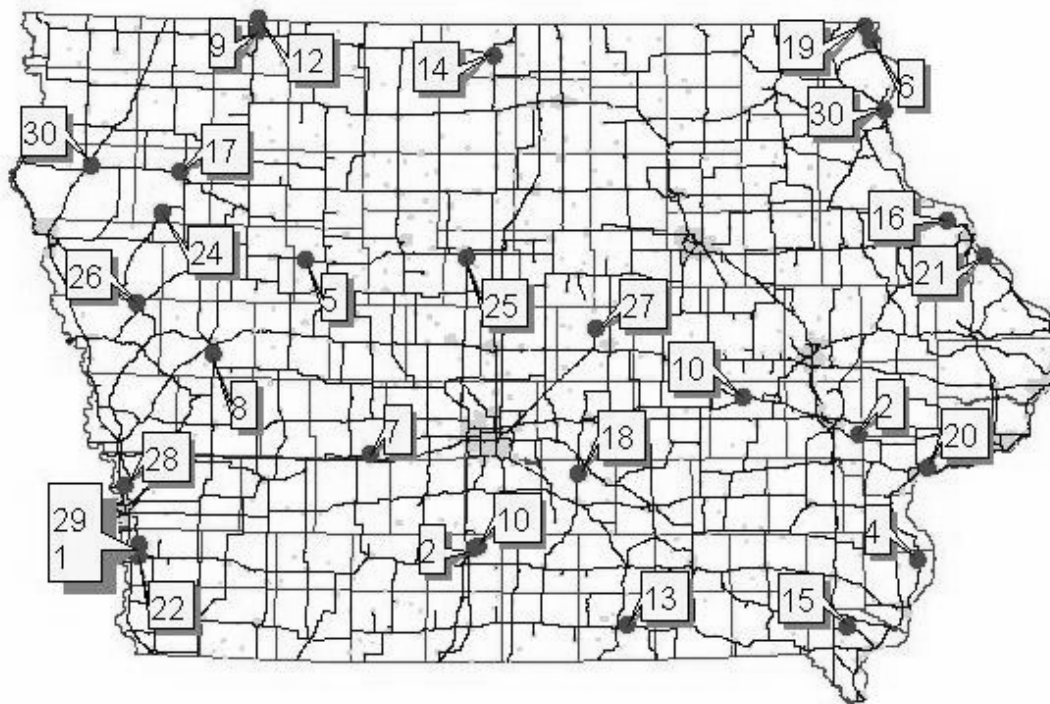
Figure 2 High Crash Locations —Rural Curves

Figure 3 High Crash Location—Rural Curves (No. 2)

Table 6 High Crash Locations—Secondary Road Curves (Story County)

County Rank	Total Crashes	Freq. Rank	Crash Rate (MVM)	Rate Rank	Dollar Loss	Loss Rank
1	1	7	157.24	3	16,000	6
2	19	1	12.07	16	111,726	2
3	1	7	86.73	5	10,700	8
4	1	7	179.03	2	5,000	12
4	1	7	61.40	9	24,500	5
6	1	7	728.75	1	3,000	14
7	2	4	7.55	18	42,000	3
7	3	3	3.23	21	374,000	1
9	1	7	82.79	6	4,000	13
10	1	7	100.46	4	2,000	16
11	6	2	1.84	23	26,900	4
12	1	7	44.40	10	3,000	14
13	1	7	5.93	20	13,500	7
13	2	4	6.61	19	8,000	11
15	1	7	39.39	12	1,500	18
16	1	7	33.10	14	1,600	17
16	1	7	74.86	7	500	24
18	1	7	70.50	8	500	24
19	2	4	9.36	17	1,000	19
20	1	7	1.36	25	10,500	9
20	1	7	43.36	11	503	23
20	1	7	27.50	15	1,000	19
23	1	7	35.93	13	600	22
24	1	7	0.67	28	9,000	10
25	1	7	2.82	22	1,000	19
26	1	7	1.78	24	500	24
27	1	7	1.21	26	500	24
28	1	7	1.15	27	500	24

Figure 4 High Crash Locations—Secondary Road Curves (Story County)

4.1.2   Fixed-Object Crashes

The top 30 high fixed-object struck crashes are presented in Table 7. Crash locations are presented in Table 8 and Figure 5. Figure 6 presents an example large-scale, site-specific map useful in precisely identifying a problem location for field review. The objects included in fixed-object crash analysis are all 18 fixed-object struck crashes listed in GIS-ALAS (e.g., building, ditch, guardrail). Moreover, locations with less than three fixed-object crashes were excluded in this analysis based on the assumption that two crash occurrences at a location in 10 years (i.e., 1989–1998 crash data) would not potentially be significant.

Similar tables and figures can be provided for each fixed-object struck type. For example, Table 9 shows the top 30 locations of utility pole struck crashes. Crash loca tion are presented in Table 10 and Figures 7–10. Similarly, locations with less than three utility poles struck crashes were excluded in this analysis. Figure 11 presents an example large-scale, site-specific map useful in precisely identifying a problem location for field review.

Table 7 High Crash Locations—Collisions with Fixed Objects

Statewide Rank	Total Crashes	Freq. Rank	Crash Rate (MVM)	Rate Rank	Dollar Loss	Loss Rank
1	23	27	35.45	89	1,292,203	55
2	10	241	87.99	28	1,690,828	32
3	13	132	164.67	19	479,803	374
4	39	7	37.78	82	355,617	468
5	31	9	11.05	386	928,059	177
6	51	2	13.50	310	647,712	332
7	10	241	11.26	374	543,103	353
8	34	8	14.99	272	229,865	755
9	14	101	5.79	672	517,728	362
10	17	65	5.34	708	458,857	379
11	9	311	9.64	437	395,650	422
12	6	695	28.50	115	454,800	381
13	8	391	62.58	49	228,300	758
14	6	695	7.45	535	1,759,253	26
15	7	514	7.48	530	844,300	215
16	44	5	5.31	710	288,777	545
17	9	311	27.55	123	184,100	831
18	9	311	5.59	687	819,710	282
19	13	132	2.80	1149	1,813,168	24
20	5	977	166.98	18	804,791	322
21	12	163	3.23	1035	984,375	128
22	8	391	4.64	783	945,650	155
23	14	101	4.35	820	408,600	410
24	12	163	3.12	1061	1,003,850	122
25	5	977	15.20	264	993,200	124
26	8	391	4.56	791	886,373	185
27	15	87	4.23	837	332,703	479
28	6	695	6.78	587	985,753	126
29	9	311	3.42	990	1,007,700	121
30	10	241	3.58	958	836,353	229

Table 8 High Crash Locations—Collisions with Fixed Objects (Descriptions)

Statewide Rank	County/City	Route	Approximate Location*
1	Harrison/—	IA 183	I-680 to US 30
2	Johnson/—	340th St	Black Hawk Ave to Johnson Iowa Rd
3	Clarke/—	US 69	US 152 to US 65
4	Monroe/Albia	IA 5	IA 5 and IA 137 interchange
5	Polk/Des Moines	Scott Ave	SE 11th St to SE 12th St
6	Scott/Davenport	W 5th St	Scott Ave to Ripley St
7	Harrison/—	Austin Ave	260th St to I-29
8	Johnson/Iowa City	Iowa Ave	N Madison St to US 6
9	Clay/—	350th St	240 Ave to 260 Ave
10	Polk/Des Moines	I-235	W River Dr to I-235
11	Cerro Gordo/—	300th	Pheasant to US 65
12	Linn/—	Ross Rd	Old Ferry Rd to N
13	Scott/—	210th St	80 Ave to 90 Ave
14	Dubuque/—	Massey St	Old Massey Rd to US 52
15	Greene/—	237th	Jordan Ave to Kirkwood Ave
16	Pottawattamie/ Council Bluffs	US 6	IA 192 to IA 192
17	Warren/Norwalk	80th Ave	Beardsley St to No Name Rd
18	Des Moines/—	IA 99	Mediapolis Rd to 230th St
19	Humboldt/—	Paragon Ave	140th St to 150th St
20	Lee/—	212 Ave	320th St to White Plains Rd
21	Mills/—	US 275	Goode Ave to Glenview Ave
22	Muscatine/—	231st St	Seven Springs Rd to Burlington Rd
23	Polk/Des Moines	Riverside Dr	Court Ave to No Name Rd
24	Polk/Des Moines	I-235	I-235 to 42nd SW
25	Polk/Des Moines	IA 5	SW 30th St to SW 28th Ct
26	Plymouth/—	C60	Pioneer Ave to Polk Ave
27	Polk/Des Moines	Dean Ave	E 36th Rd to Iowa State Fairgrounds
28	Pottawattamie/—	Mahogany Rd	I-80 to 280th St
29	Worth/—	I-35	IA 9 to B 15
30	Dubuque/—	US 20	No Name St to IA 136

*High crash location may be limited to a portion of the location described.

Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.

Figure 5 High Crash Locations—Collisions with Fixed Objects

Figure 6 High Crash Locations—Collisions with Fixed Objects (No. 1)

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Table 9 High Crash Locations—Collisions with Utility Poles

Statewide Rank	Total Crashes	Freq. Rank	Crash Rate (MVM)	Rate Rank	Dollar Loss	Loss Rank
1	8	8	1.28	27	193,200	16
1	8	8	2.27	12	147,200	31
3	9	4	0.58	51	1,090,250	2
4	9	4	0.55	56	303,003	10
5	5	27	0.65	45	985,500	3
6	7	15	0.76	40	157,803	23
7	6	20	2.15	16	56,700	51
8	4	43	1.89	20	154,500	25
9	3	74	2.33	11	850,000	4
10	5	27	1.63	23	138,503	40
11	8	8	0.81	37	95,885	48
12	11	3	0.31	83	333,503	9
12	4	43	4.59	7	129,300	45
14	8	8	1.00	35	49,200	55
15	4	43	0.93	36	155,500	24
15	6	20	0.60	50	144,503	33
17	4	43	0.55	57	836,050	5
18	7	15	0.31	82	297,500	11
19	5	27	0.48	63	167,500	19
20	8	8	0.64	46	47,150	56
21	9	4	0.62	49	46,200	58
22	4	43	2.07	17	54,460	52
23	6	20	0.56	55	139,300	38
24	5	27	1.71	22	39,000	65
25	5	27	0.52	59	149,500	29
26	4	43	0.76	41	143,450	36
27	9	4	0.24	96	161,203	21
28	5	27	0.29	89	397,450	6
29	15	1	0.23	98	154,300	26
30	7	15	0.45	67	105,103	47

Table 10 High Crash Locations—Collisions with Utility Poles (Descriptions)

Statewide Rank	County/City	Route	Approximate Location*
1	Muscatine/Muscatine	IA 92	Green St to Elm St
1	Muscatine/Muscatine	LeRoy St	Amherst St to Orange St
3	Dubuque/Dubuque	IA 20	Hill St to IA 946
4	Polk/Des Moines	Hickman Rd	Chautauqua Pkwy to Nash Dr
5	Polk/Des Moines	35th St	Kingman Blvd to Rutland Ave
6	Polk/Des Moines	33rd E	E Washington Ave to E Jefferson Ave
7	Scott/Davenport	Telegraph Rd	Waverly Rd to 3rd St
8	Polk/—	NW 6 Dr	NE 44 Ave to NW 43 Ave
9	Scott/Bettendorf	Utica Ridge Rd	Crow Creek Rd to Terrace Park Dr
10	Polk/Des Moines	IA 163	US 69 to E 15th St
11	Scott/Davenport	Waverly Rd	N Lincoln to Telegraph Rd
12	Polk/Des Moines	US 6	New York to Sheridan Ave
12	Polk/Des Moines	Wedgewood Rd	E 26th St to 29th E
14	Johnson/Iowa City	IA 1	Brown St to Governor St
15	Johnson/Iowa City	Keokuk St	Florence St to Keokuk Ct
15	Muscatine/Muscatine	IA 92	Elm St to Ash St
17	Pottawattamie/ Council Bluffs	Madison Ave	S 1st St to Kappel St
18	Polk/Des Moines	IA 163	E 16th St to McCormick St
19	Polk/Des Moines	US 69	SE 14th Ct to US 69
20	Polk/Des Moines	M. L. King Jr. Pkwy	Allison Ave to Franklin Ave
21	Polk/Des Moines	Grand Ave E	E 22nd St to E 22nd St
22	Shelby/Harlan	Willow St	Onyx Dr to 12th St
23	Polk/Des Moines	McKinley Ave E	SE 3rd St to SE 4th St
24	Scott/Davenport	Telegraph Rd	S Elsie Ave to S Concord
25	Polk/Des Moines	University Ave	E 12 St to E 13 St
26	Polk/Des Moines	Fleur Dr	Rittenhouse St to County Line Rd
27	Polk/Des Moines	Maury St	SE 23rd St to SE 23rd Ct
28	Polk/Des Moines	Grand Ave	56th St to 51st St
29	Tama/Davenport	N Division St	W 34th St to George Washington Blvd
30	Polk/Des Moines	Saylor Rd	E Jefferson Ave to Guthrie Ave

*High crash location may be limited to a portion of the location described.

Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.
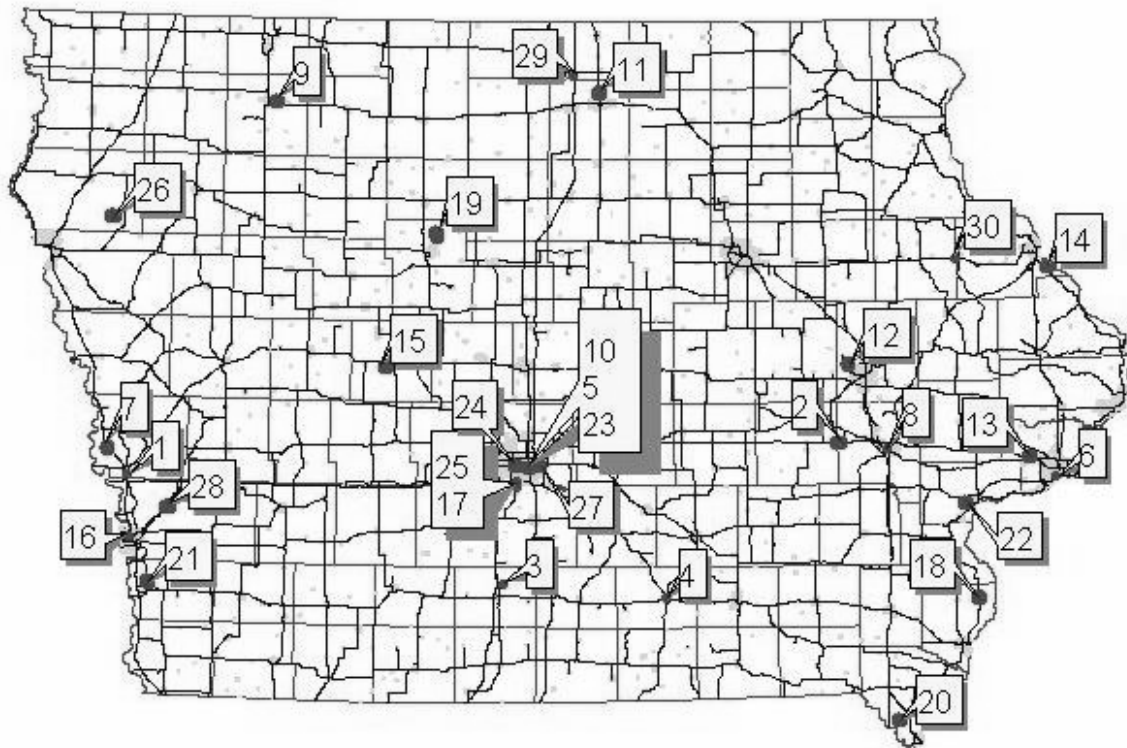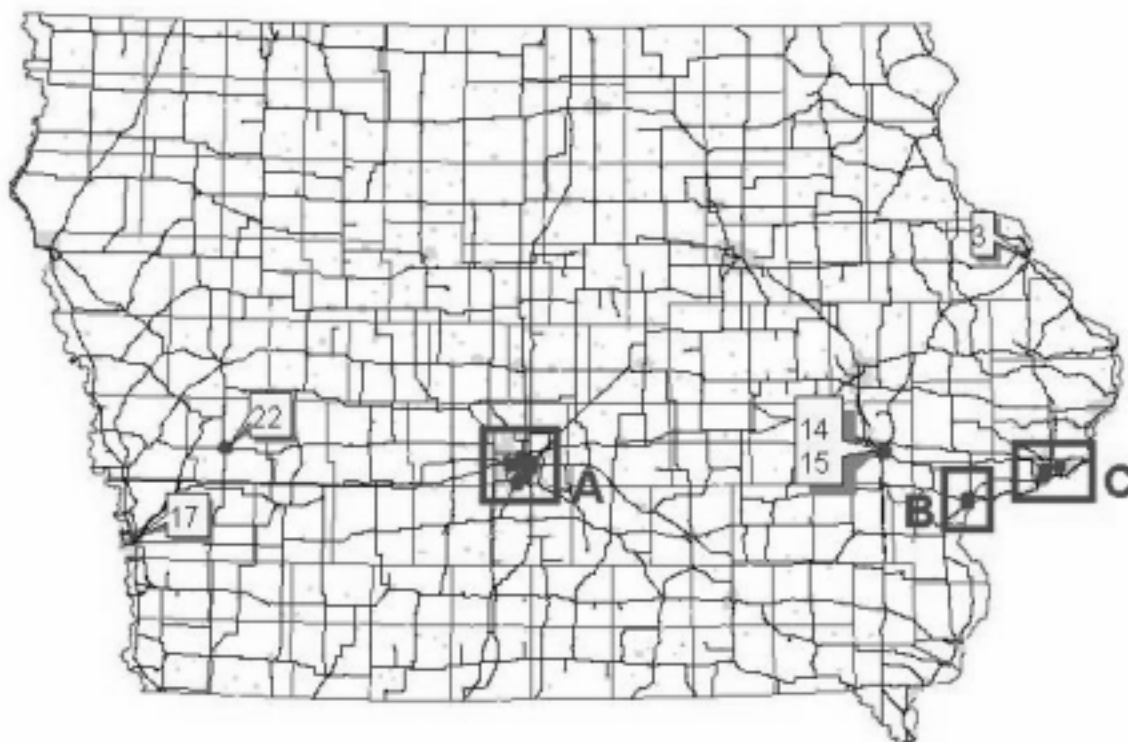
Figure 7 High Crash Locations—Collisions with Utility Poles
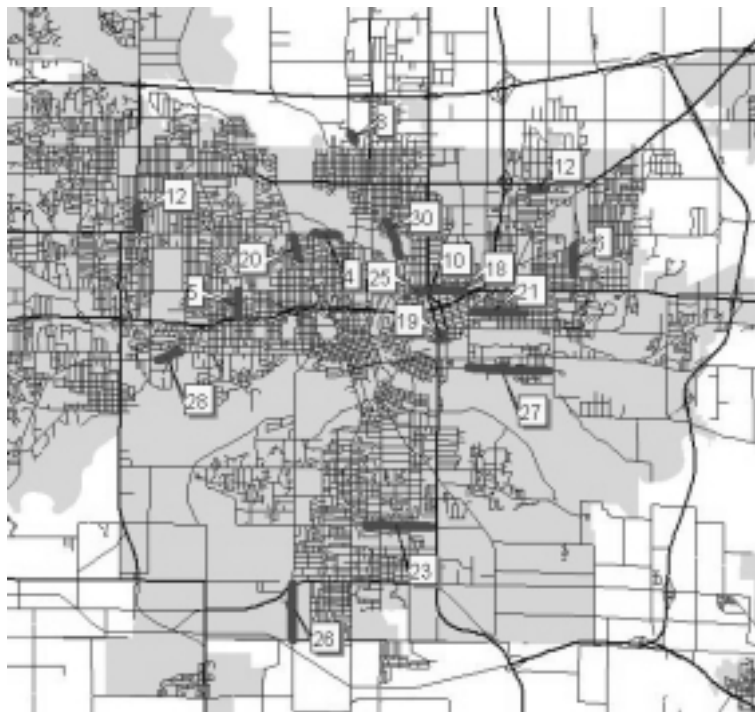
Figure 8 High Crash Locations—Collisions with Utility Poles, Des Moines Area ("A")
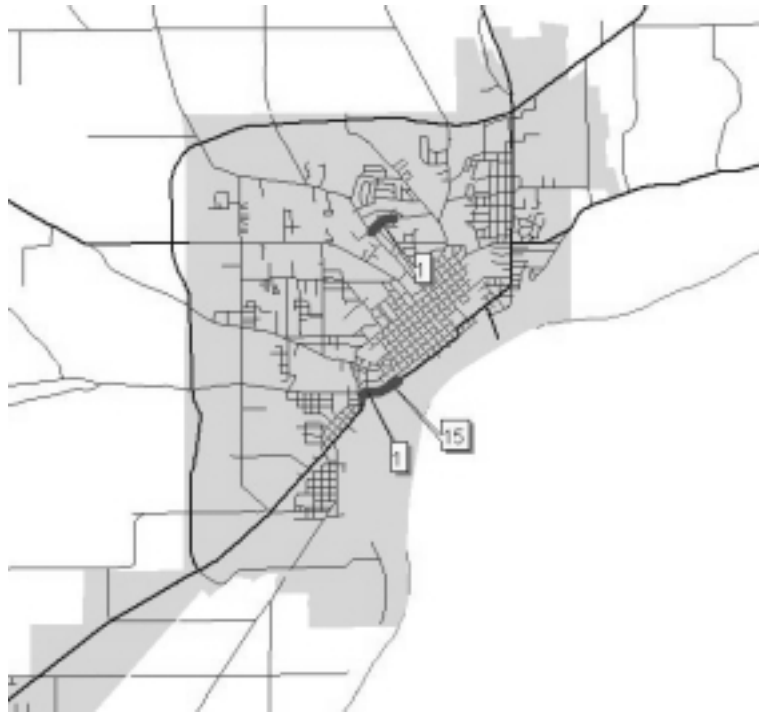
Figure 9 High Crash Locations—Collisions with Utility Poles, Muscatine Area ("B")
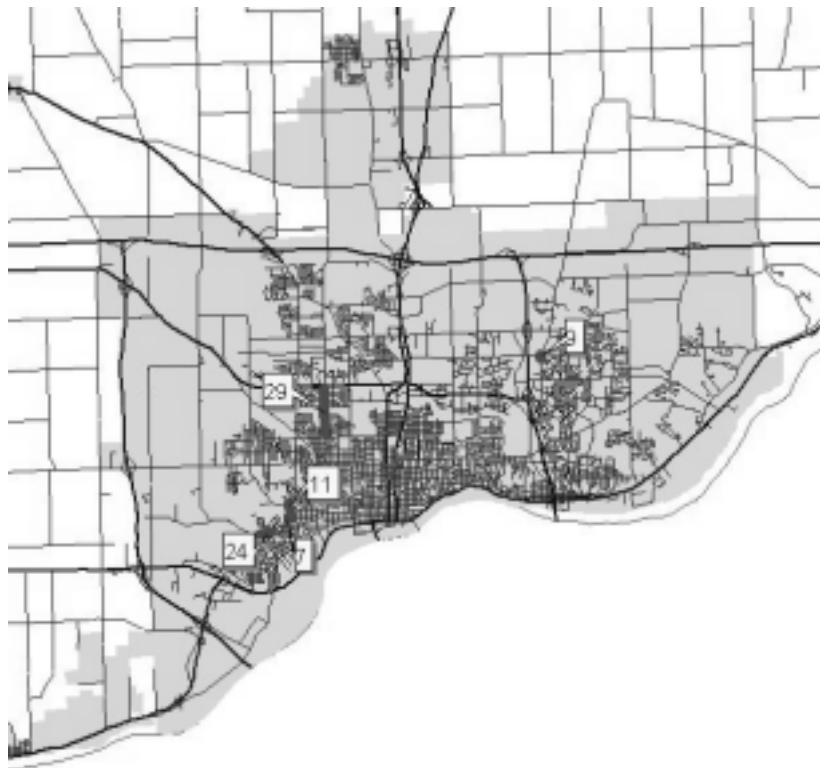
Figure 10 High Crash Locations—Collisions with Utility Poles, Davenport Area ("C")

Figure 11 High Crash Locations—Collisions with Utility Poles (No. 1)

4.1.3   Rural Four-Lane Expressway Intersections

Table 11 and Figure 12 present the top 30 high crash rural four-lane expressway intersections. These intersections may have been improved during or after the analysis period; therefore, Iowa DOT personnel familiar with the specified intersections should make a final qualitative assessment of their rankings. The locations (county, route, intersecting route) of these intersections are presented in Table 12 and Figure 12. Figure 13 presents an example large-scale, site-specific map useful in precisely identifying the intersection location for field review.

Table 11 High Crash Locations—Rural Four-Lane Intersections

Statewide Rank	Total Crashes	Freq. Rank	Daily Entering Vehicles	Crash Rate (MEV)	Rate Rank	Dollar Loss	Loss Rank
1	27	2	11,240	1.32	3	4,062,478	1
2	25	4	12,100	1.13	6	1,781,200	5
3	21	5	11,800	0.98	10	2,099,263	2
4	31	1	14,750	1.15	5	1,182,328	12
5a	20	6	6,780	1.62	2	1,079,900	14
5b	13	11	6,900	1.03	7	1,924,700	4
7	26	3	14,455	0.99	9	835,003	21
8	13	11	9,805	0.73	15	1,294,206	9
9	14	10	11,095	0.69	19	1,535,951	7
10	11	18	8,660	0.70	18	2,084,300	3
11	15	7	8,280	0.99	8	348,709	30
12	13	11	5,950	1.20	4	303,700	32
13	11	18	7,660	0.79	12	974,900	18
14	9	23	6,650	0.74	14	1,037,503	16
15	15	7	16,550	0.50	43	1,204,503	11
16	12	15	10,905	0.60	26	528,009	24
17	12	15	8,605	0.76	13	191,253	41
18	7	31	5,880	0.65	23	1,006,000	17
19	13	11	9,875	0.72	16	172,265	47
20	12	15	13,490	0.49	45	792,950	23
21	9	23	9,265	0.53	35	191,300	40
22	6	37	7,915	0.42	59	1,648,050	6
23	7	31	8,140	0.47	47	316,000	31
24	5	47	6,150	0.45	53	1,239,200	10
25	15	7	12,185	0.67	21	49,603	86
26	8	27	7,570	0.58	28	127,003	71
27	11	18	11,875	0.51	41	120,650	74
28	5	47	8,310	0.33	83	1,113,000	13
29	5	47	6,800	0.40	62	264,500	35
30	6	37	5,470	0.60	27	56,360	81

Table 12 High Crash Locations—Rural Four-Lane Intersections (Descriptions)

Statewide Rank	County	Route	Intersecting Route
1	Dallas	IA 141	State Street
2	Clay	US 18	US 71
3	Plymouth	US 75	C 38
4	Polk	IA 163	NE 80th St
5a	Crawford	US 59	Arrowhead Rd
5b	Boone	US 30	L Ave
7	Polk	IA 163	NE 70th Street
8	Linn	US 151	Springville Rd
9	Polk	IA 163	IA 316
10	Clinton	US 30	330th Ave
11	Linn	IA 13	Central City Rd
12	Linn	IA 13	Maine Ridge Rd
13	Washington	IA 218	220th St
14	Mills	US 34	Kidd Rd
15	Polk	IA 141	NW 121st St
16	Des Moines	US 34	South Prairie Grove Rd
17	Dickinson	IA 9	IA 86
18	Dubuque	US 61	Feeney Rd
19	Black Hawk	US 63	Cedar Wapsi Rd W
20	Black Hawk	US 218	Cedar Wapsi Rd W
21	Lee	US 61	IA 16
22	Dallas	IA 141	O Ave
23	Mills	US 34	IA 949
24	Story	US 30	680th Ave
25	Harrison	US 30	Jopine Pl
26	Dallas	IA 141	IA 210
27	Boone	US 30	T Ave
28	Boone	US 30	Montana Rd
29	Delaware	US 20	310th Ave
30	Mills	US 34	IA 41

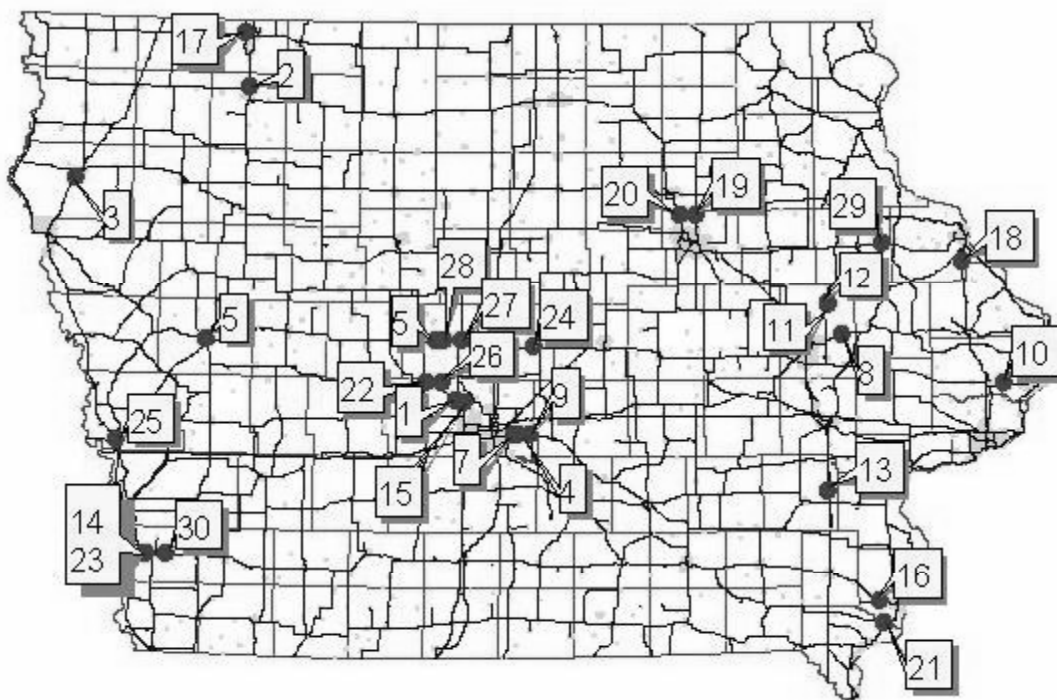*Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.*

Figure 12 High Crash Locations—Rural Four-Lane Intersections

Figure 13 High Crash Locations—Rural Four-Lane Intersections (No. 1)

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4.1.4 Head-on Crashes Due to Crossing Centerline

Table 13 shows the top 30 head-on crash locations in Iowa. Locations with less than three head-on crashes were excluded from the data set based on the assumption that two crash occurrences at a location in 10 years (i.e., 1989–1998 crash data) does not constitute a high crash location. Table 14 and Figure 14 present the locations of these crashes. Figure 15 presents the top ranked head-on crash location on a site-specific map, useful in precisely identifying a problem location for field review.

Table 13 High Crash Locations—Head-on Crashes

Statewide Rank	Total Crashes	Freq. Rank	Crash Rate (MVM)	Rate Rank	Dollar Loss	Loss Rank
1	5	3	1.23	5	2,131,300	10
2	4	8	11.39	1	973,900	26
3	4	8	0.47	21	2,555,500	7
4	4	8	0.46	22	2,235,900	9
5	3	26	1.52	4	1,794,800	12
6	3	26	0.53	14	2,447,500	8
7	5	3	0.36	33	1,221,800	18
8	9	1	0.32	40	1,320,600	16
9	5	3	2.61	2	87,100	56
10	5	3	0.20	56	3,233,800	4
11	3	26	0.33	37	2,669,000	6
12	4	8	0.60	10	142,150	53
12	8	2	0.24	49	1,158,650	20
14	3	26	0.39	28	1,186,200	19
14	3	26	0.27	46	4,828,300	1
16	3	26	0.47	20	866,000	29
17	3	26	0.23	50	4,638,750	2
17	3	26	0.35	35	1,243,000	17
19	3	26	0.40	26	971,000	27
19	3	26	0.51	16	380,003	37
21	3	26	0.42	24	853,000	30
21	3	26	0.37	32	1,060,400	22
23	5	3	0.18	65	1,664,000	14
23	4	8	0.14	71	3,441,510	3
23	4	8	0.41	25	167,900	49
26	3	26	0.88	7	165,195	50
27	3	26	0.69	8	150,050	51
28	4	8	0.43	23	106,700	55
28	3	26	0.53	13	178,000	47
30	3	26	0.47	19	178,000	47

Table 14 High Crash Locations—Head-on Crashes (Descriptions)

Statewide Rank	County	Route	Approximate Location*
1	Marion	IA 14	Between 130th Pl and Nixon St
2	Jasper	IA 392	S 76th Ave West 0.3 mi
3	Appanoose	IA 5	Between 479th St and 470 St
4	Union	US 34	Between 12 Mile Lake Dr and 2 Lakes Dr
5	Marshall	W Iowa Ave	Between Parker Ave and Oak Park RD
6	Franklin	US 65	North of Sheffield North City Limits
7	Wapello	US 34	56th Ave East 0.64 mi
8	Muscatine	US 61	Between New Era Rd and Taylor
9	Polk	NW 6th Dr	Between NW 45th Ave and NE 44th Ave
10	Des Moines	US 61	Between 170th St and Dodgeville Rd
11	Washington	IA 92	Between Juniper Ave and Lexington Blvd
12	Harrison	US 30	Between 296th St and Monroe Ave
13	Marshall	US 30	Between IA 146 and Yates Ave
14	Sioux	US 18	Between Fig Ave and Fillmore Ave
14	Jasper	Geneva Ave	Between W 70th St and No Name Rd
16	Butler	IA 14	Between Bluebird Dr and 170 St
17	Henry	US 34	Between Franklin Ave and E
17	Harrison	US 30	Between Niagara Trail and 270th St
19	Keokuk	IA 92	Between 163rd Ave and 180th Ave
19	Pottawattamie	US 6	Between 340th St and 345th St
21	Polk	NE 46th Ave	Between NE 96th St and NE 108th St
21	Black Hawk	Dunkerton Rd	Between Moline Rd and Sage Rd
23	Warren	IA 92	Between 105th Ave and Milepost 128
23	Grundy	US 20	Between X Ave and Butler Rd
23	Muscatine	US 61	Between Vail and Verde
26	Linn	E Post Rd	Between Fox Meadow Dr (North and South)
27	Appanoose	IA 2	Between 135th Ave and 140th Ave
28	Muscatine	Stewart Rd	Between 49th St and 41st St
28	Tama	US 30	Toledo West City Limit East 0.19 mi
30	Davis	US 63	Between Lime TR and Mink Blvd

*High crash location may be limited to a portion of the location described.

Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.
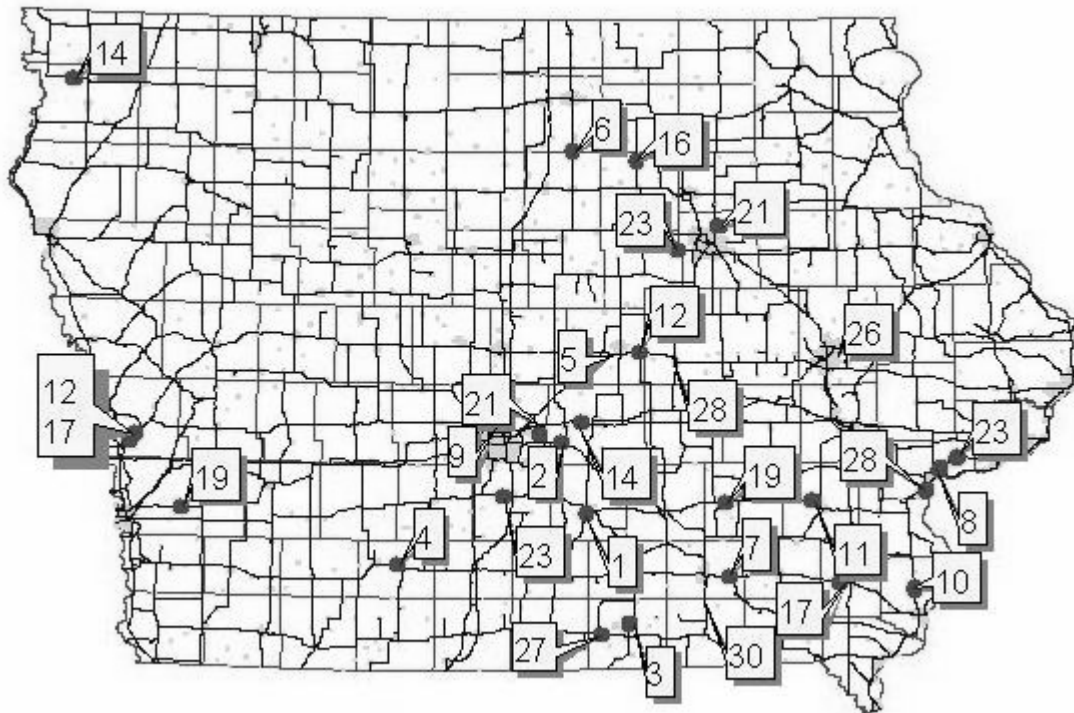
Figure 14 High Crash Locations—Head-on Crashes

Figure 15 High Crash Locations—Head-on Crashes (No. 1)

4.1.5 Urban Four-Lane Undivided Corridors

Table 15 presents the top 30 four-lane undivided corridors with high crash occurrences. The results of this analysis may be used to identify corridors requiring mitigation (e.g., median improvements, turn-lane additions, widening, and three-lane cross section). Table 16 and Figure 16 present the locations of these corridors. Table 17 presents the top 30 partial corridors (or complete homogeneous corridors) with high crash occurrences. Table 18 and Figure 17 present the locations of these partial corridors. All problem corridors contain at least one partial corridor ranked in the top 30. In addition, the highest-ranking location is the same in both lists. Figures 18 and 19 present example, large-scale maps of partial corridor location, and ranking, with respect to overall corridor location and ranking.

Table 15 High Crash Locations—Four-Lane Undivided Corridors

Statewide Rank	Total Crashes	Total Int. Crashes	Freq. Rank	Length (mile)	Weighted AADT	Crash Rate	Rate Rank	Dollar Loss	Loss Rank
1	408	350	2	1.07	11,389	5.50	3	3,949,700	3
2	595	418	1	1.61	11,208	5.42	4	3,197,651	7
3	321	217	5	1.44	9,815	3.73	20	3,302,310	5
4	293	224	6	1.06	12,189	3.73	21	2,688,118	11
5	219	183	13	0.74	12,293	3.96	19	2,730,642	9
6	284	184	8	1.42	10,389	3.16	32	3,828,411	4
7	334	247	4	1.81	10,382	2.92	38	3,202,990	6
8	260	217	11	1.34	6,810	4.68	10	1,546,562	34
9	283	216	9	1.73	8,936	3.01	35	2,121,264	19
9	293	194	6	2.02	8,641	2.76	43	2,488,020	14
11	362	266	3	2.58	9,837	2.34	65	4,898,772	2
12	122	78	42	0.51	13,499	4.95	7	1,895,620	25
13	219	189	13	1.52	8,685	2.73	47	2,449,840	15
14	178	161	22	0.48	11,076	8.81	1	1,120,793	58
15	169	100	26	1.01	8,160	3.37	27	1,586,278	31
15	189	126	18	0.78	10,946	3.64	23	1,343,848	43
15	165	75	28	0.92	9,886	2.98	36	2,053,327	20
18	140	98	35	1.16	5,932	3.34	28	1,964,487	22
19	191	148	16	1.84	6,187	2.76	44	1,387,522	40
20	98	85	59	0.35	11,900	4.51	12	1,603,450	30
20	265	165	10	2.44	8,010	2.23	70	1,970,714	21
22	90	77	64	0.45	10,654	4.63	11	1,826,223	27
22	171	129	25	1.43	7,470	2.63	49	1,769,009	28
24	179	143	21	1.06	13,515	2.05	78	2,585,861	12
25	174	104	24	1.15	11,566	2.15	73	2,182,094	18
26	198	122	15	0.92	12,129	2.92	39	1,071,737	63
27	190	142	17	0.90	9,334	3.72	22	760,103	81
28	220	136	12	2.00	7,204	2.51	58	1,208,981	53
29	142	129	34	1.52	5,984	2.57	55	1,468,191	37
30	182	127	20	0.98	11,118	2.75	45	1,073,060	62

Table 16 High Crash Locations—Four-Lane Undivided Corridors (Descriptions)

Statewide Rank	City	Route	Location
1	Davenport	US 61	W 15th St to W River Dr
2	Clinton	US 67	S 4th St to 7th Ave to 13th Ave N
3	Estherville	IA 9	N 20th St to WN 1st
4	Carroll	US 30	Carol St to Monterey Dr
5	Mason City	US 65	6th St SE to 17th St SE
6	Cherokee	US 59	Main St to Unnamed Rd
7	Marshalltown	IA 14	Leo St to E Anson St
8	Oskaloosa	US 63	Glendale Rd to 1st Ave E
9	Mount Pleasant	US 34	Marion St to Harrison St
9	Centerville	IA 5	E Grant St to Green St
11	Sioux Center	US 75	7th St NW to 9th St SW
12	Des Moines	IA 63	E 15th St to Easton BLVD
13	Mason City	US 65	25th St NW to 5th St NW
14	Dubuque	US 52	E 17th St to E 9th St
15	Storm Lake	IA 914	590th St to Milwaukee Ave
15	Osceola	US 34	Ridge Rd to S Main St
15	Algona	US 169	US 18 to Oak St
18	Glenwood	US 275	6th St to Hazel St
19	Perry	IA 144	IA 141 to Willis Ave
20	Knoxville	IA 14	Pleasant St to Larson St
20	Keokuk	US 136	N 7th St to S 2nd St
22	New Hampton	US 18	Underwood St to US 63
22	Clinton	US 30	Washington Blvd to W
24	Muscatine	IA 92 & 38	Mulberry Ave to Washington St
25	Fairfield	US 34	S 9th St to S 20th St
26	Oskaloosa	IA 92	US 63 to IA 432
27	Waverly	IA 3	4th St NW to 18th St NW
28	Red Oak	IA 48	Ohio Ave to Alix Ave
29	Grinnell	IA 6	Prince St to Penrose St
30	Denison	US 30	20th St to 9th St S

Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.
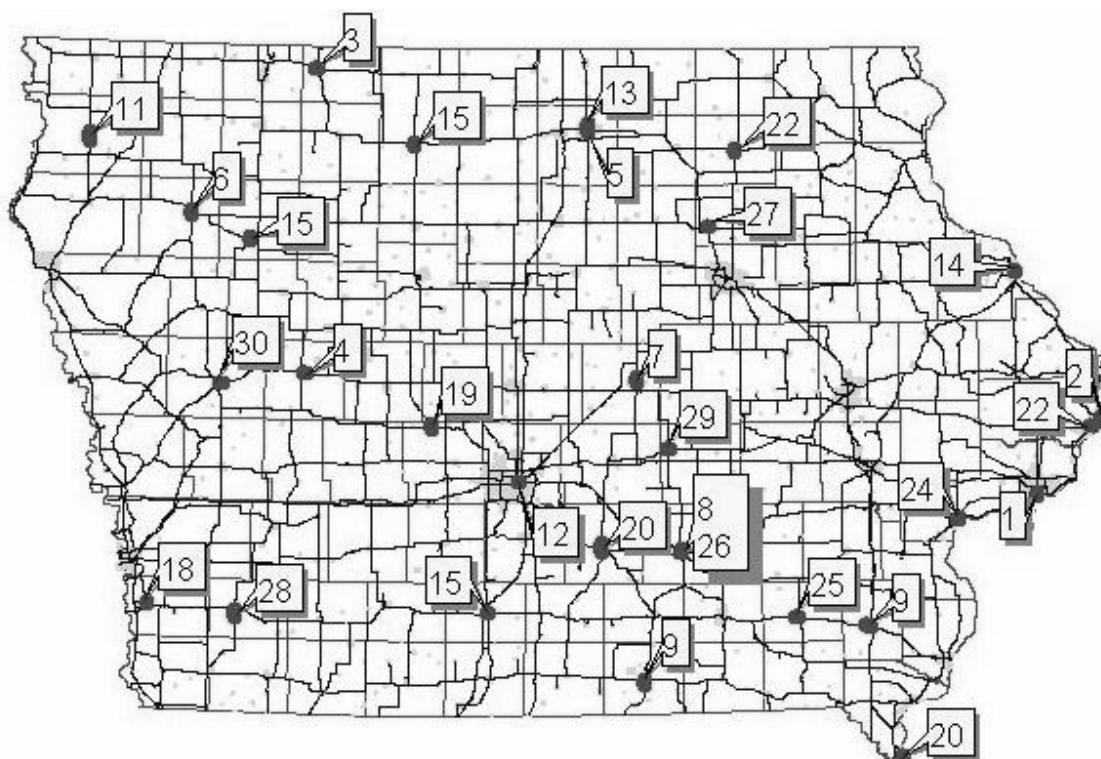
Figure 16 High Crash Locations—Four-Lane Undivided Corridors

Table 17 High Crash Locations—Partial Four-Lane Undivided Corridors

Statewide Rank	Total Crashes	Total Int. Crashes	Freq. Rank	Length (mile)	Weighted AADT	Crash Rate	Rate Rank	Dollar Loss	Loss Rank
1	408	350	1	1.07	11,389	5.50	10	3,949,700	2
2	249	202	7	0.51	10,623	12.84	1	1,598,264	26
3	293	224	3	1.06	12,189	3.73	34	2,688,118	6
4	261	200	5	0.84	12,258	4.17	29	2,283,246	11
5	260	217	6	1.34	6,810	4.68	20	1,546,562	29
6	313	198	2	1.00	13,115	3.92	32	1,645,918	22
7	122	78	31	0.51	13,499	4.95	15	1,895,620	16
8	118	85	36	0.57	8,442	7.66	5	1,625,670	24
9	203	132	9	0.87	10,715	3.58	38	1,676,640	20
10	178	161	17	0.48	11,076	8.81	4	1,120,793	53
11	293	194	3	2.02	8,641	2.76	64	2,488,020	9
12	89	47	64	0.58	8,386	5.82	7	2,647,404	7
13	140	98	27	1.16	5,932	3.34	44	1,964,487	13
14	219	189	8	1.52	8,685	2.73	67	2,449,840	10
15	193	140	12	0.99	12,181	2.63	71	2,936,690	3
16	169	100	19	1.01	8,160	3.37	43	1,586,278	27
17	99	90	55	0.37	11,000	4.93	16	1,656,441	21
18	189	126	14	0.78	10,946	3.64	37	1,343,848	42
19	90	77	61	0.45	10,654	4.63	22	1,826,223	18
20	98	85	56	0.35	11,900	4.51	23	1,603,450	25
21	120	93	34	0.37	13,586	4.84	17	1,074,201	57
22	131	115	28	0.22	6,436	11.15	2	826,588	80
23	195	137	11	0.84	11,772	3.24	51	1,181,007	51
24	151	105	23	0.39	9,011	9.18	3	725,145	90
25	103	86	48	0.57	8,089	6.98	6	951,703	69
26	104	24	46	0.56	10,413	5.47	11	959,795	68
26	97	61	57	0.51	13,800	3.85	33	1,389,567	35
28	113	66	42	0.52	11,159	5.55	9	861,397	76
28	198	122	10	0.92	12,129	2.92	57	1,071,737	60
30	142	129	25	1.52	5,984	2.57	77	1,468,191	32

Table 18 High Crash Locations—Partial Four-Lane Undivided Corridors (Descriptions)

Statewide Rank	City	Route	Location
1	Davenport	US 61	W 15th St to W River Dr
2	Mount Pleasant	US 34	Harrison St to Marion St
3	Carroll	US 30	Carroll St to Monterey Rd
4	Marshalltown	IA 14	E State St to E Anson St
5	Oskaloosa	US 63	1st Ave E to Glendale Rd
6	Clinton	US 67	13th Ave N to 2nd Ave S
7	Des Moines	IA 163	E 15th St to Easton Blvd
8	Estherville	IA 9	N 20th St to 13th No
9	Estherville	IA 9	13th No to WN 1st
10	Dubuque	US 52	E 9th St to E 17th St
11	Centerville	IA 5	E Grant St to Green St
12	Cherokee	US 59	E Bow Dr to Unnamed Rd
13	Glenwood	US 275	Hazel St to 6th St
14	Mason City	US 65	5th St NW to 25 St NW
15	Sioux Center	US 75	7th St NW to 9th St SW
16	Storm Lake	IA 914	590th St to Milwaukee Ave
17	Mason City	US 65	17th S SE to 11th S SW
18	Osceola	US 34	Ridge Rd to S Main St
19	Clinton	US 30	Washington Blvd to W
20	Keokuk	US 136	N 7th St to S 2nd St
21	Mason City	US 65	11th S SW to 6th St SE
22	Clinton	US 67	S 4th St to 7th Ave
23	Cherokee	US 59	E Bow Dr to Main St
24	Clinton	US 67	7th Ave to 2nd Ave S
25	Perry	IA 144	IA 141 to Willis Ave
26	Algona	US 169	Oak St to US 18
26	Fairfield	US 34	S 20th St to 9th St
28	Knoxville	IA 14	Pleasant St to Larson St
28	Oskaloosa	IA 92	US 63 to IA 432
30	Grinnell	IA 6	Prince St to Penrose St

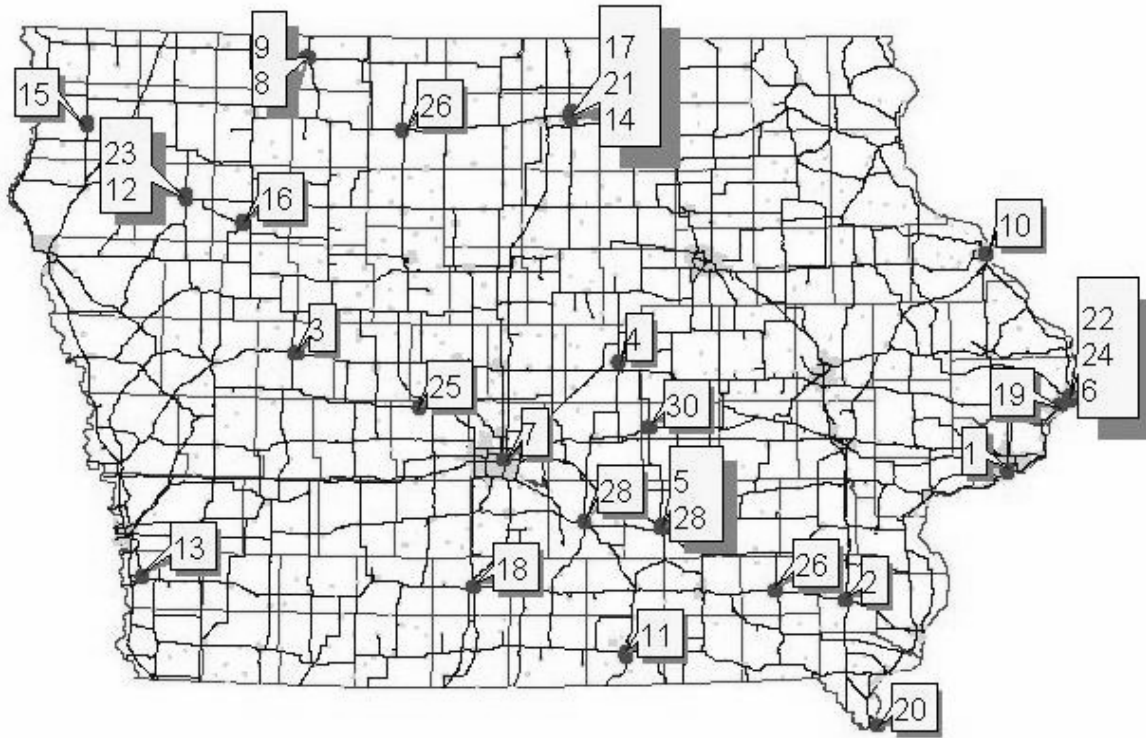*Source: January 1999 GIMS snapshot. Roadway geometry at some locations may have changed.*

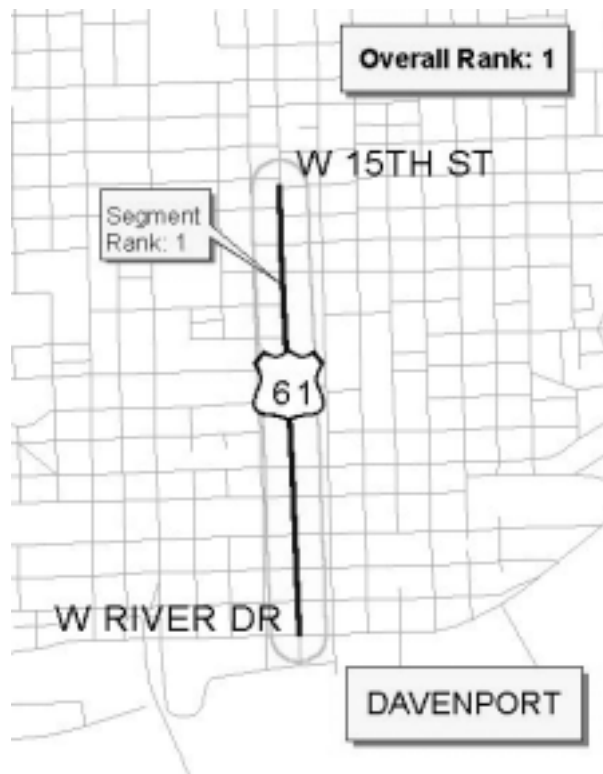**Figure 17 High Crash Locations—Partial Four-Lane Undivided Corridors**

Figure 18 High Crash Locations—Four-Lane Undivided Corridor (No. 1)

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Figure 19 High Crash Locations—Four-Lane Undivided Corridor (No. 2)

and Component Segments

4.2 Causal Factors and Regression Analysis

4.2.1 Head-on Crashes Due to Crossing Centerline

A total of 3,246 GIMS sections were appropriate for analysis of head-on crashes. These segments were distributed across different types of highway systems as shown in Table 19 (second column). Most of the segments were located on farm-to-market roads followed by Iowa highways. Interstate segments were not considered in head-on crash analysis. Mean crash rates were calculated on these segments as reported in Table 19. The overall average crash rate on all types of facilities was 1.154 crashes per million-vehicle-mile (MVM). The highest crash rate was observed on local roads. These roads typically carry low traffic volume as evidenced by the low mean AADT (only 730 vehicles). Hence, the occurrence of very few crashes results in relatively high crash rates. The second highest crash rate was on farm-to-market roads followed by Iowa highways, while the lowest crash rate was on US highways. It appears that higher functional classification highways have lower head-on crash rates. Table 19 also shows mean length for the segments considered in this study, and overall the average length was about one kilometer.

Table 19 Segment Characteristics for Head-on Crashes

Type of System	Number of Segments	Mean Crash Rate (MVM)	Crash Rate Std. Dev.	Mean AADT (veh)	Mean Segment Length (m)
US Hwy	998	0.289	0.402	4379	910
IA Hwy	1070	0.479	1.229	2846	977
Farm to Mkt	1085	1.080	2.121	1302	1095
Local	93	19.06	47.252	730	645
All	3246	1.154	8.656	2741	987

A statistical comparison was also performed to ascertain whether the mean head-on crash rates were different across different types of highway systems. Results for significance of differences in the mean head-on crash rates among different highway systems are reported in Table 20. A *t*-statistic of ± 1.96 indicates statistical significance at the 95 percent confidence level. All *t*-statistics are significant indicating that crash rates are statistically different among the different types of highway systems.

Table 20 Differences in Head-on Crash Rate Means (*t*-statistic)

Type of System	US Hwy	IA Hwy	Farm to Mkt	Local
US Hwy	—	0.189 (4.768)	0.790 (12.046)	18.773 (3.831)
IA Hwy	—	—	0.601 (8.068)	18.583 (3.793)
Farm to Mkt	—	—	—	17.982 (3.670)
Local	—	—	—	—

After determining that crash rates were different on various types of highways, the second step was to estimate linear regression models for head-on crash rates and isolate segment-related characteristics that affect them. Tables 21–23 present head-on crash rate models on US highways, Iowa highways, farm-to-market roads, and local roads, respectively. A positive coefficient in the model indicates that head-on crash rates increase as values of the independent variable increase, and a negative coefficient indicates that crash rates decrease with increasing values of the independent variable. The reported models are the best that the research team members could obtain from the data. Each model is discussed below.

Table 21 presents the model for head-on crash rates on US highways with a relatively low *R*-squared value. The low *R*-squared value indicates that there are other variables (e.g., driver and vehicle characteristics) besides the ones included in the model that account for crash rates. Despite the low *R*-squared value, the model does provide some useful information on segment-related characteristics that affect head-on crash rates. For example, speed limit on US highways has a negative coefficient and is statistically significant at the 95 percent confidence level. This indicates that US highways with higher speed limit have a lower head -on crash rate. Highways with higher speed limits are usually constructed to higher geometric standards and, therefore,

may be safer. The model indicates that terrain also affects head-on crash rate on US highways (the confidence level is 90 percent—a t-statistic of ±1.64 indicates statistical significance at this level). Specifically, head-on crash rates are lower in flat terrain compared to rolling or hilly terrain. The model also shows that crash rates go down with increasing values of total shoulder width (i.e., the sum of inside and outside shoulder widths). Wider shoulders on highways allow drivers to steer away from each other and this may be a reason for lower head-on crash rates on US highways with wider shoulders. The international roughness index (IRI) was used in the model, but it showed no significant effect on head-on crash rates.

Table 21 Head-on Crash Rate Model for US Highways

Independent Variable	Coefficient	t-statistic
Constant	0.885	0.101
Speed limit	-0.0056	-2.051
Flat terrain	-0.0498	1.945
Total shoulder width	-0.0159	-1.667
IRI	3.4439	0.196

Note: R-squared = 0.011.

Table 22 shows the regression model of head-on crash rates for Iowa highways. The same model specification as in the US highway model was used. The model has a relatively low R-squared value, indicating that there may be other factors besides the ones included in the model that affect head-on crash rates. The statistically significant variables in the model are speed limit, total shoulder width, and IRI. The model shows that Iowa highways with higher speed limit tend to have a lower head-on crash rate. Similarly, highways with wider inside and outside shoulders have a lower crash rate. These two findings are similar to those in for US highways. Additionally, highways with higher IRI values tend to have higher head-on crash rates. The model indicates that surface condition of an Iowa highway affects the head-on crash rate.

Table 22 Head-on Crash Rate Model for Iowa Highways

Independent Variable	Coefficient	t-statistic
Constant	2.701	4.417
Speed limit	-0.0245	-3.55
Flat terrain	-0.1092	-1.433
Total shoulder width	-0.0626	-2.631
IRI	0.0011	2.736

Note: R-squared = 0.052.

Table 23 shows the model for head-on crash rate on farm-to-market roads. Again, the value of R-squared is relatively low. The model has two variables that are statistically significant at the 90 percent level. First, highways with wider shoulders tend to have a lower head-on crash rate (as on US and Iowa highways). Second, the model shows that highways with unpaved shoulders (i.e., shoulders of earth or gravel) tend to have a higher head-on crash rate. This may be because drivers find it easy to take evasive maneuvers to avoid an oncoming vehicle if the shoulders are paved. Unpaved earthen shoulders may also slow down evading vehicles ifthere is significant amount of moisture in the soil material.

Table 23 Head-on Crash Rate Model for Farm-to-Market Roads

Independent Variable	Coefficient	t-statistic
Constant	1.7648	2.83
Speed limit	-0.0062	-0.871
Flat terrain	-0.2049	-1.549
Total shoulder width	-0.0958	-1.758
IRI	-0.0025	-0.965
Unpaved shoulders	0.2811	1.821

Note: R-squared = 0.009.

Based on this model, Figure 20 presents locations along farm-to-market roadway that are likely to experience a higher rate of head-on crashes. Furthermore, paving or shoulder widening at these locations may reduce the number of head-on crashed due to crossing the centerline. Given these types of improvements, corrective activities would not likely be limited to these specific locations but be applied along logically defined corridors.
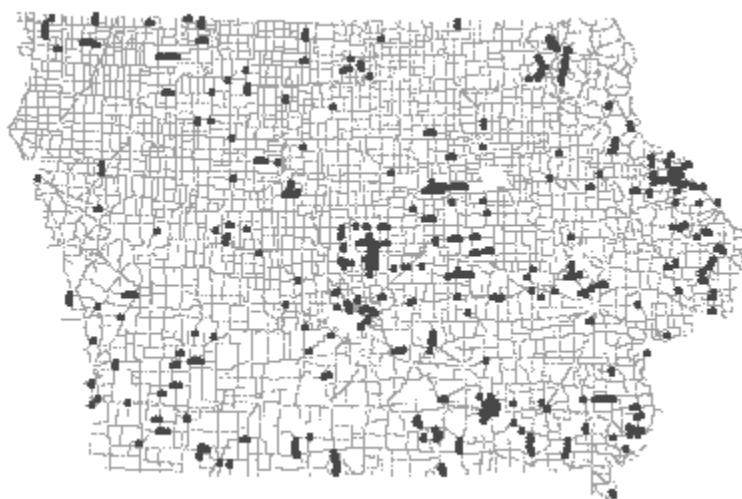

Figure 20 Farm-to-Market Roads with Potentially Higher Head-on Crash Rates

Table 24 presents the head-on crash rate model for local roads. Although, the R-squared value is slightly better than the previous models, no particular segment-related characteristic is statistically significant. The only two variables with some explanatory power are terrain and the IRI. However, nothing can be said regarding their effect on the head-on crash rate from a statistical viewpoint.

Overall, it seems that head-on crash rates are higher on lower classification (e.g., local and farm-to-market) highways. Rates appear to depend on the highway speed limit, terrain, shoulder width, paved or unpaved shoulders, and the IRI value. Given the relatively low R-squared values for the models, it is likely that other non-segment related characteristics may further account for head-on crash rates. Non-segment related characteristics could not be tested because information on those was not available in the database used for this research project. It would be prudent to

extend this research and take into account facility age and /or non-segment related characteristics to isolate factors responsible for high crash rates.

Table 24 Head-on Crash Rate Model for Local Roads

Independent Variable	Coefficient	*t*-statistic
Constant	-9.4469	-0.385
Speed limit	0.1332	0.458
Flat terrain	15.8273	1.594
Total shoulder width	3.0457	0.846
IRI	0.1031	1.5863
Unpaved shoulders	3.9293	0.326

Note: R-squared = 0.103.

4.2.2 Fixed-Object Crashes

A total of 44,244 GIMS sections were appropriate for analysis of fixed-object crashes. Of these, the majority belonged to local roads followed by farm-to-market roads (see Table 25). Relatively few segments belonged to the Interstate highway system. The average fixed-object crash rate was 6.7 crashes per MVM. As in the case of head-on crashes, the fixed-object crash rate on local roads was the highest followed by farm-to-market roads. The lowest crash rate was on US highways followed by the Interstate highways. The least AADT was on farm-to-market roads followed by AADT on local roads. AADT was highest on Interstate highways. The mean segment length was 0.82 km.

Table 25 Segment Characteristics for Fixed-Object Crashes

Type of System	Number of Segments	Mean Crash Rate (MVM)	Crash Rate Std. Dev.	Mean AADT (veh)	Mean Segment Length (m)
Interstate	1518	0.946	3.345	24231	518
US Hwy	5049	0.729	3.808	7507	600
IA Hwy	5427	1.047	6.356	3939	735
Farm to Mkt	11534	4.027	18.740	636	1148
Local	20716	11.561	41.889	1801	741
All	44244	6.707	30.694	3108	823

Results of statistical testing by means of Tukey's *t*-tests on differences in mean fixed-object crash rates across different types of highways are presented in Table 26. The results indicate that the crash rate on US highways was significantly lower than the rate on Interstate highways. However, there was not enough difference in the crash rate between Interstate and Iowa highways. Tests indicated that there were significant differences in fixed-object crash rates among the other types of highways.

Fixed-object crash rate models are presented in Tables 27–31. Table 27 shows the model for Interstate highways with an *R*-squared value of 0.245. The model indicates that Interstate highway segments in flat and rolling terrain tend to have higher crash rates compared to segments in hilly terrain. Similarly, segments with asphalt cement concrete (ACC) pavement

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surface tend to experience higher crash rates compared to other types of surfaces. Segments with paved shoulders have lower fixed-object crash rates, where as segments with no median barrier tend to have higher fixed-object crash rates.

Table 26 Differences in Fixed-Object Crash Rate Means (*t*-statistic)

Type of System	Interstate	US Hwy	IA Hwy	Farm to Mkt	Local
Interstate	—	-0.216 (-2.142)	0.1009 (0.829)	3.081 (15.842)	10.615 (34.982)
US Hwy	—	—	0.317 (3.076)	3.177 (3.128)	10.831 (36.603)
IA Hwy	—	—	—	2.980 (15.309)	2.980 (15.309)
Farm to Mkt	—	—	—	—	7.534 (22.202)
Local	—	—	—	—	—

Table 27 Fixed-Object Crash Rate Model for Interstate Highways

Independent Variable	Coefficient	*t*-statistic
(Constant)	1.3607	4.541
Flat terrain	0.8505	4.845
ACC pavement	0.3086	2.014
Paved shoulders	-2.0060	-7.087
Rolling terrain	1.2003	5.650
No barrier	3.2231	14.519

Note: R-squared = 0.245.

Table 28 presents the fixed-object crash rate model for US highways. The model has a relatively low R-squared value, indicating that there may be other independent variables (possibly non-segment related) that may account for fixed-object crash rates. The only two significant variables in the model (at the 90 percent confidence level) are the presence of no barrier and surface width. The absence of median barriers tends to increase fixed-object crash rates. The negative estimated coefficient of surface width indicates that fixed-object crash rates tend to be lower on wider US highways, as expected.

Table 28 Fixed-Object Crash Rate Model for US Highways

Independent Variable	Coefficient	*t*-statistic
Constant	0.8405	4.536
Paved shoulders	0.2474	1.057
No barrier	0.2357	1.872
Surface width	-0.0346	-1.918

Note: R-squared = 0.001.

Based on this model, Figure 21 presents locations along US Highways that are likely to experience a higher rate of fixed-object crashes. This, of course, does not take into consideration the actual number and location of fixed-objects at these locations.
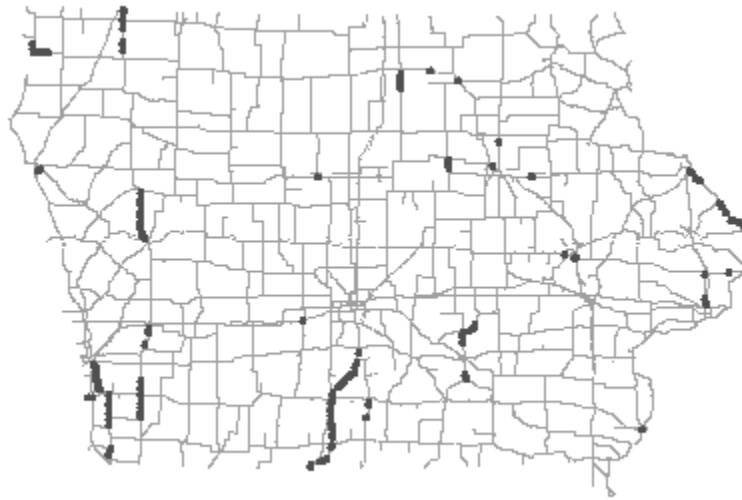

Figure 21 US Highways with Potentially Higher Fixed-Object Crash Rates

Fixed-object crash rate model for Iowa highways is presented in Table 29. Again, the R-squared value is rather low. Two independent variables in the model are statistically significant. Segments in flat terrain tend to have lower fixed-object crash rates while highways with combination pavement appear to have higher fixed-object crash rates.

Table 29 Fixed-Object Crash Rate Model for Iowa Highways

Independent Variable	Coefficient	t-statistic
Constant	0.7070	2.368
No barrier	0.3900	1.262
Flat terrain	-0.3206	-1.706
Combination pavement	1.1698	3.436

Note: R-squared = 0.003.

The model for farm-to-market roads (see Table 30) shows that segments with ACC and portland cement concrete (PCC) pavements tend to have lower fixed-object crash rates, while segments with earthen shoulders tend to have higher fixed-object crash rates. The statistical significance for the latter variable is at the 90 percent level.

Finally, the model for fixed-object crash rate on local roads has a low R-squared value (see Table 31). Nonetheless, the model indicates that several independent variables as statistically significant in explaining fixed-object crash rates. Local road segments in flat terrain tend to have higher fixed-object crash rates, while ACC and PCC segments tend to have lower rates. Similarly, segments with greater number of lanes (a proxy for surface width) tend to have lower fixed-object crash rates. Higher speed limits on local roads tend to result in higher fixed-object

crash rates. Segments with earthen shoulders tend to have higher fixed-object crash rates though the variable is statistically not significant.

Table 30 Fixed-Object Crash Rate Model for Farm-to-Market Roads

Independent Variable	Coefficient	*t*-statistic
Constant	6.7805	2.746
Speed limit	0.0162	0.581
ACC pavement	-6.9317	-17.462
PCC pavement	-6.5437	-13.435
Shoulder type (earth or gravel)	0.6165	1.723

Note: R-squared = 0.029.

Table 31 Fixed-Object Crash Rate Model for Local Roads

Independent Variable	Coefficient	*t*-statistic
Constant	17.1885	8.155
Flat terrain	1.8017	1.943
ACC pavement	-10.6321	-9.251
PCC pavement	-11.1118	-9.159
Number of lanes	-1.9274	-3.768
Speed limit	0.0613	2.591
Shoulder type (earth or gravel)	0.8622	1.324

Note: R-squared = 0.031.

Overall, data analysis indicated that fixed-object crash rates tend to be higher on lower classification (local and farm-to-market) highways. It appears that terrain, type of pavement, paved or unpaved shoulders, the absence of median barriers, surface width, and number of lanes tend to affect fixed-object crash rates on different types of highways. The models had rather low R-squared values, indicating the possibility that facility age and/or other non-segmental characteristics may further explain fixed-object crash rates.

4.2.3   Horizontal Curves

The model developed to examine the impact of the curve length and degree of curvature on crashes is presented in Table 32. Despite the low R-squared value, the model shows strong relationships between the curve length and degree of curvature and horizontal curve crash rates.

The model shows that the degree of curvature has a direct impact on crash rate increments on horizontal curves. That is, the crash rate significantly increased with increased degree of curvature. Furthermore, the model indicates that the crash rate on shorter curve lengths is significantly higher than the crash rate on longer curves. This is probably because sharp curves are usually shorter than mild curves (*33*).

Table 32 Horizontal Curve Crash Rate Model

Independent Variable	Coefficient	*t*-statistic
(Constant)	1.5604	12.77
Degree of curvature	0.0649	3.99
Curve length	-0.0004	-3.89

Note: *R*-squared = 0.0134.

5 CONCLUSIONS AND RECOMMENDATIONS

In Iowa, as in most states, highway engineering safety improvement programs are reactive. In other words, safety countermeasures are applied to the roadway only after high crash rates have been observed. The objective of this project was to quantify the impact of highway geometry and design features on crash rates, enabling agencies to proactively identify and mitigate *future* problem areas.

The application of GIS in this project has enabled the research team to identify and analyze roadway segments characterized by specific criteria that are not identified by conventional crash analysis. Along the way, methods were developed for solving intermediate problems that will also find utility at state DOTs (e.g., determining most recent daily entering vehicles at intersections and reviewing and defining extents or location specific analysis). Another useful product is an improved corridor analysis methodology.

The project produced the following items:

- curve database for Iowa, with radii and length attributes
- procedures for identifying high crash locations of five types
- statistical models of the relationship between geometric features and crash rates
- candidate lists (maps and tables) for improvement (Iowa top 30 lists) for five problem types

ACKNOWLEDGMENTS

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Appendix A
Iowa DOT High Crash Location Ranking Procedure

The Iowa DOT generates an annual list of top 100 high crash locations using a five-year period statewide crash data (The latest ranking uses the 1994–1998 crash data). The crash locations consist of nodes and links. The following roadway facilities have been classified as nodes:

- intersections
- ramp terminals
- railroad crossings
- grade separation structures
- bridges
- road ends
- 90 degree turns (when each leg is at least quarter mile long)
- county lines
- major signalized commercial entrances

Links are the distances between adjacent nodes. Crashes assigned to a link do not include the crashes assigned to either of the two nodes.

To become an initial candidate location, a site needs to meet one of the following three criteria: one fatal crash, four injury crashes, or a total of eight crashes. Once the candidate locations have been determined, a three-phased ranking scheme is used as the basis to determine the high crash locations (see flow diagram, Figure 1).
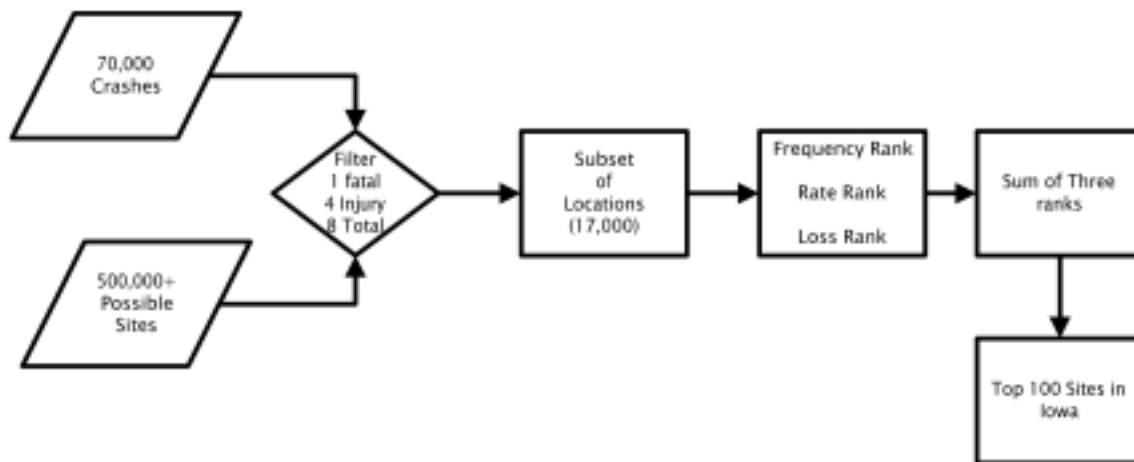

Figure 1 Current Approach to Identify High Crash Locations in Iowa

1 Crash Frequency

The first ranking is based on the number of crashes, or frequency, occurring at each location. Each site is given a ranking based on the number of crashes. A site that has the highest frequency of crashes receives the number one ranking. In the case of a tie, each location receives the same rank and the subsequent ranking is skipped.

2 Crash Rate

Second, each site is ranked according to the crash rate. For nodes and links up to 0.6 miles, the crash rate is calculated using the following equation:

$$\text{Crash Rate/MEV} = \frac{\text{Number of Crashes}}{\text{DEV}} \times \frac{1000000}{5 \times 365 \,\text{days/year}}$$

where

MEV is million entering vehicles, and
DEV is daily entering vehicles for nodes or average daily traffic (ADT) for links.

For links 0.6 miles or longer, the DEV is determined using the following equation:

$$\text{DEV} = \text{ABS}\left[\frac{\text{Link Length}}{0.3}\right] \times \text{DEV}$$

The site that has the largest crash rate receives the top ranking. The same implication of a tie applies to this ranking as well. For locations where their traffic volumes are unknown the ranking of zero is assigned.

3 Crash Loss

Finally, each site is ranked according to the financial loss from the crashes. This is determined by using values based on the injuries sustained in each crash type as seen in Table 1. These values are then multiplied by the number of people that fall into each category. For example, if two fatalities, four major injuries, 12 minor injuries, and 15 possible injuries occur at a location, the value loss due to injuries is $2,206,000 ($2 \times \$800,000 + 4 \times \$120,000 + 12 \times \$8,000 + 15 \times \$2,000$).

Table 1 Crash Costs by Injury Type

Type	Dollar Value
Fatal	$800,000
Major Injury	$120,000
Minor Injury	$8,000
Possible Injury	$2,000

Property damage is incorporated as well. Officers report estimates on the crash report form. In some instances there is no estimate of property damage; when this occurs a default value of

$2,000 is used. All of these values are summed up and result in a ranking based on the value lost at each location.

To determine the top 100 high crash locations within the state, each of the three ranks are added together and a final ranking is performed with the lowest cumulative ranking receiving the highest ranking of a 1. Those falling within the top 100 ranking are deemed high crash locations within Iowa. An example of this process is shown in Table 2, using fictitious data, for the top 13 locations throughout the state. This process is performed for approximately 17,000 locations that meet the initial threshold.

Table 2 Example of High Crash Location Ranking Process

Reference Node	# of Crashes	Rank	Crash Rate	Rank	Dollar Loss	Rank	Total Rank	Statewide Rank
11111111	47	5	2.63	23	2,327,237	15	5+23+15 = 43	1
33333333	29	31	Unknown	0	1,909,420	20	31+0+20 = 57	2
44444444	25	35	2.76	15	2,734,603	9	35+15+9 = 59	3
22222222	24	37	2.71	19	3,150,760	4	37+19+4 = 60	4
55555555	53	1	2.46	29	1,373,300	35	1+29+35 = 65	5
77777777	40	10	2.92	8	1,120,949	47	10+8+47 = 65	5
00000000	34	21	2.40	33	2,000,850	18	21+33+18= 72	7
10101010	49	2	2.65	21	1,117,965	50	2+21+50 = 73	8
32323232	28	32	2.41	32	2,684,259	10	32+32+10= 74	9
88888888	19	51	3.15	3	1,824,587	22	51+3+22 = 76	10
99999999	18	53	2.47	28	3,501,985	1	53+28+1 = 82	11
66666666	36	18	2.28	41	1,740,548	27	18+41+27= 86	12
21212121	32	24	1.98	61	1,357,951	39	26+61+39 =124	13

As indicated, crash frequency, rate, and cost equally contribute in ranking of the top 100 high crash locations. It was also noted that in current ranking procedure roadway links are treated as nodes. A link length of less of 0.6 miles is not taken into the consideration in the crash rate calculation. It is only for the longer link (0.6 miles or greater) where the link length is employed in a form of a multiplier (Link Length / 0.3), rather than the actual link length, in the crash rate equation.

Appendix B
Horizontal Curve Identification Strategies

1 Glossary

Quantitative Assessment - Accuracy level of the method – one minus type I error plus type II error

Type I Error - H_1 is selected as being correct when H_0 is correct

Type II Error - H_0 is selected as being correct when H_1 is correct

- H_0: not a curve
- H_1: a curve

    Through the visual inspection of the sites' maps in the GIS environment, each record is marked as being a curve or a line. The discrepancies between the two procedures define the two error types.

    Type I error is the percent of records that have been tagged as curves, but the visual inspections indicate differently.

    Type II error (i.e., a more serious error) is the percent of records that have been tagged as not curves, but the visual inspections indicate differently.

Fixed Cost - Training and development cost

Marginal Cost - Changes in cost for an additional site study

Qualitative Assessment - What are the implications if we make mistakes

2   Curve Identification Procedures Overview

2.1   Preliminary Technique I - County Tested

In its first version, the curve identification technique determined the best combination of strategies as well as appropriate threshold values for the string's "weighed-difference" (see the description of Length (string) strategy in Appendix B), deflection angle, and segment length through a trail-and-error analysis. For example, using the following logical statement, the curves' segments were identified. Figure 1 shows the identified segments in Story County, Iowa.

(((([Dfbearing]>5) and ([Flegs]=2) and
([Dfbearing]<>999)) or
(([Dtbearing]>5) and ([Tlegs]=2) and
([Dtbearing]<>999)) or
(([Dfbearing]>5) and ([Dfbearing]<80)) or
(([Dtbearing]>5) and ([Dtbearing]<80)) or
(([Dfbearing]>80) and ([Flegs]=2) and
([Dfbearing]<>999)) or
(([Dtbearing]>80) and ([Tlegs]=2) and
([Dtbearing]<>999)) or
(([Sdiffer] < -3) and ([Length] < 400))) and
([Func]<50)
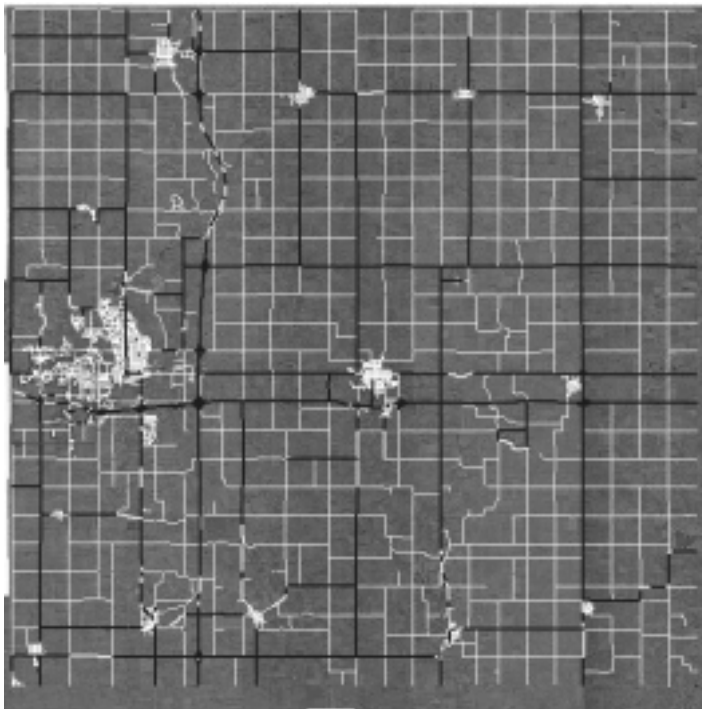
Figure 1 Identified Curves' Segments Using

{B-2 OR [L (st) AND L (seg)]}

Once the lines' segments filtered out, the identified curves' segments were visually inspected. The visual curve identification process relies primarily on three data sets: aerial photography, roadway cartography (with associated roadway characteristics), and Roadware® driven lane centerline data. The latter two provide the components necessary to calculate curve characteristics, e.g. length, radius, and degree. Everywhere, aerial photography provides the best representation of roadway alignment, allowing the user to better identify curve extents on the cartographic and Roadware® representations of the roadway. An analyst could also manually measure pertinent curve characteristics from these images, but this would be a labor-intensive process.

In Iowa, Roadware® data provides the next best representation of roadway alignment. As part of the Iowa Pavement Management Program (IPMP), Roadware® uses a differential GPS equipped vehicle to collect pavement condition data along a portion of Iowa's highway network. These data are summarized to 100-meter segments of roadway and, when plotted, provide a relatively "smooth" representation of the roadway as driven (accurate to within approximately five meters). Roadware® data, however, are not available for all roadways and may not be continuous due to loss of signal or data reduction errors.

The last data set, cartography, is available statewide for all roadways. Important roadway characteristics, such as traffic, are also associated with these data. Roadway alignment and changes in alignment (including curves) are represented by a series of variable length line segments. Therefore, curve extents can be difficult to identify from this data set alone. The accuracy of these data range from approximately 12 to 50 meters.
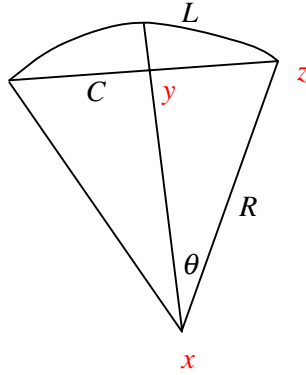
In general, aerial photography and Roadware® lane centerline data provide the best representations of actual roadway alignments, facilitating more accurate curve identification. Moreover, Roadware® data will likely yield more accurate curve measurements. However, these data are not available for all roadways and do not possess essential roadway characteristics. Cartography serves as a comprehensive data set, fulfilling all necessary data requirements.

Next, the following steps were conducted to calculate curve radii and degree of curvature:

- Eliminate the mistakenly selected tangent segments through visual inspections
- Manually put boxes around curves
- Perform clipping
  - Assign a unique number to each polygon
  - Assign the polygon unique numbers to the curves
  - Calculate the length of curve
  - Calculate weighted AADT
- Combine the clipped segments
- Calculate chord and curve lengths
- Calculate the curve radii and degrees of curvature

The first two steps are performed manually. In the first step, all selected segments were inspected for possible errors. The mistakenly selected segments were eliminated and polygons were placed around remaining curves using the procedure described in Appendix C.

Finally, a closed form solution was used to calculate the curves' radii and degrees. Using circular curve equations (Equations 1 and 2), Equation 3 is derived to define the relationship between the length and chord length of the curves. Equation 3 is a function of θ (i.e., half of the deflection); thus, it can be rearranged into Equation 4. Equation 4 and its derivative (Equation 5) are then plugged into the Newton iteration equation (Equation 6) to estimate θ. This, in turn, facilitates the calculation of the radius and degree of a curve (R and D) through the use of Equations 1 and 7, respectively.

$$L = 2R\theta \tag{1}$$

$$\frac{C}{2} = R\sin\theta; \text{ see triangle xyz} \tag{2}$$

$$\frac{C}{L} = \frac{\sin\theta}{\theta} \tag{3}$$

$$f(\theta_n) = \frac{\sin\theta_n}{\theta_n} - \frac{C}{L} \tag{4}$$

$$f'(\theta_n) = \frac{\cos\theta_n}{\theta_n} - \frac{\sin\theta_n}{\theta^2_n} \tag{5}$$

$$\theta_{n+1} = \theta_n - \frac{f(\theta_n)}{f'(\theta_n)}; \text{ n} = 0, 1, 2,... \tag{6}$$

$$D = \frac{5729.579}{R} \tag{7}$$

where

       L = Curve length
       C = Chord length
       R = Curve radius
       D = Curve degree
       $\theta = \dfrac{\Delta}{2}$; Δ = Deflection angle

As shown in the table below, the values of θ's converge rather rapidly.

C (ft)	L (ft)	Theta (0)	Theta (1)	Theta (2)	Theta (3)	Theta (4)	Theta (5)	Theta (6)	R (ft)	D (deg)
949	963	1	0.52189	0.343226	0.29917	0.296007	0.29599	0.29599	1626.74	3.52
943	961	1	0.53581	0.371941	0.33786	0.336188	0.33618	0.33618	1429.28	4.01
416	427	1	0.55916	0.417759	0.3953	0.394685	0.39468	0.39468	540.94	10.59
780	790	1	0.51565	0.329986	0.28043	0.276148	0.27611	0.27611	1430.56	4.01
774	788	1	0.53261	0.365435	0.32931	0.327377	0.32737	0.32737	1203.53	4.76

2.2 Preliminary Technique II - Statewide Tested

Due to limited time and resources, statewide curve identification was confined to potential "problem" curves or consecutive curves. In this technique, only primary road crashes reported by the officer in the field as occurring on a curve were selected.[1] After visually inspecting identified sites, polygons were placed around isolated curves, consecutive curves, and their influence areas. Figure 2 shows a polygon around an isolated curve. Curves were defined by estimating the locations of their point of curvature (PC) and point of tangency (PT). Curve influence areas were defined as extending approximately 200 meters longitudinally, along the adjacent tangents, from these points.[2] If the influence area of consecutive curves overlaps, the curves were included in a single polygon.

The remaining steps, beginning with "perform clipping", are essentially the same as the steps defined in version 1. Because of the aforementioned curve selection criteria (i.e., selecting only the potential "problem" curves), calculations of the curves' characteristics (i.e., chord and curve lengths, radius, and degree) were not applicable to this technique. The detail procedure is presented in Appendix C.

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[1] The Iowa DOT will no longer maintain the [Road_geome] field in the A Crash Records. The [Road_geome] field contains crash site geometric information reported by the on site officer. The final report will provide an alternative strategy (or strategies) for future initial identification of curves.
[2] L. Reudiger, B. Psarianos, and T. Mailaender. Highway Design and Traffic Safety Engineering Handbook, McGraw Hill, NY, 1999, Table 12.2.
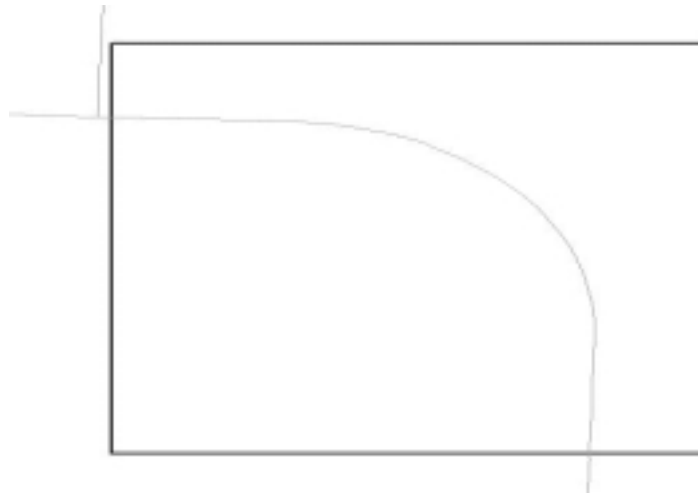
Figure 2 Example: A Polygon Drawn Around an Isolated Curve

2.3   Enhanced Technique I - County Tested

To improve the quality of the curves' characteristics, the analysis was limited to primary and secondary paved roadways throughout a county (e.g., Story county). These roadways were selected using Iowa DOT roadway centerline cartography (with associated base records attributes) and visually inspected to identify horizontal curve locations. Aerial photographs were used in conjunction with the roadway cartography to provide a more accurate representation of roadway alignment.

Upon identifying a possible curve location, lines of tangency were temporarily drawn along the roadway alignment presented by the aerial photographs. Curves were then defined by manually digitizing a line string (polyline) beginning and terminating at the approximate points of tangency. These digitized curves should provide better overall curve lengths and chord distances than when using cartography alone.

Next, a polygon was placed around the newly digitized curve and an adjacent portion of existing roadway cartography of the same approximate length and alignment. All attributed crashes were also included within the polygon extents. A unique identifier was assigned to each polygon, and the curves contained within each polygon. (Curves within the same polygon shared the same curve identifier.) The curve polygons were then used to clip and extract roadway attributes from cartography and assign these data, included weighted traffic values, to the digitized curves. Crash data were also summarized based on the unique curve identifier and assigned to the digitized curves. Digitized curve chord distance and length were calculated within GIS. Using these values, the closed form solution (presented in Equations 1 through 7) calculated curve radius and degree of curvature.

3   Detailed Curve Identification Procedures

3.1   On-curve Crashes (String-based)

3.1.1   Definition
A string is tagged as a curve when at least 50 percent of its associated accident records are designated as "on-curve" accidents.

3.1.2   Cost

	Manpower (days)			
	Ali	Zach	Student	Amount ($)
Fix cost	10	5	2	
Marginal cost	1	1	4	

3.1.3   Qualitative Assessment
This strategy may result in over estimation of horizontal curves' crash rates.
- All accidents on a designated curve are considered as "on-curve" even though only 50 percent of those were actually reported as on-curve accidents.
- An entire length of a designated string is considered as the curve length when only a section of the string is actually curved.

3.1.4   Procedure
- Open a new View
- Click on Add Theme icon
- Select *road* and *accident* shape files

Spatial join the *road* and *accident* attributes tables
- Highlight *road* theme by clicking on its text in the View
- Click on Open Theme Table to open *road* attributes table
- Highlight *accident* theme by clicking on its text in the View
- Click on Open Theme Table to open *accident* attributes table
- Click on [Shape] field of the *road* attributes table
- Click on [Shape] field of the *accident* attributes table
- Click on Join icon

The *road* attribute table closes. The new *accident* attributes table now includes all related roadway geometric data for each accident record.

Count the total number of accidents on each string
- Click on the new accident attributes table to make it active
- Click on Query Builder icon
- Input the following expression in the dialog box

   [Distance] < 6.769

- Click on [Road_link] field of the new *accidents* attributes table
- Click on Field Menu/Summarize

- Click OK to save the new table (*sum1.dbf*)
- Rename the [Count] field to [all_count] using Table/Properties/Alias Menu

Count the on-curve accidents on each string
- Click on the new accident attributes table to make it active
- Click on Query Builder icon
- Input the following expression in the dialog box

  *[Road_geometry] = 4 or [Road_geometry] = 5 or [Road_geometry] = 6
  and [Int_class] = 0 and [Distance] < 6.769*

- Click on [Road_link] field of the new *accidents* attributes table
- Click on Field Menu/Summarize
- Click OK to save the new table (*sum2.dbf*)
- Rename the [Count] field to [curve_count] using Table/Properties/Alias Menu

Calculate percent of on-curve accidents for each string
- Click on [Road_link] field of the *sum1.dbf* table
- Click on [Road_link] field of the *sum2.dbf* table
- Click on Join icon

The *sum1.dbf* table closes. The s*um2.dbf* table now has both the [all_count] and [curve_count] field
- Click Table Menu/Start Editing
- Click Edit Menu/Add field
- Name the new field [%on-curve]
- Select the [%on-curve] field and click on Calculate icon
- Enter the following expression

$$1 - \frac{[all\_count] - [curve\_count]}{[all\_count]}$$

By performing a query and equating the [%on-curve] field equal or greater than 0.50, the selected strings will be designated as "curves."

3.1.5   Illustration
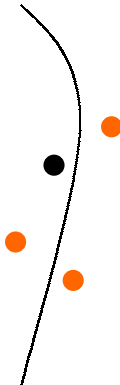
3.2   On-Curve Crashes (Segment-based)

3.2.1   Definition

A string consists of a number of segments. A segment is tagged as a curve when at least 50 percent of its associated accident records are designated as "on-curve" accidents. By examining the status of the segments prior and after the marked segment with respect to their on-curve accident percentages, this strategy could lead to determination of the beginning and end of a curve.

3.2.2   Cost

	Manpower (days)			
	Ali	Zach	Student	Amount ($)
Fix cost	10	5	3	
Marginal cost	1	1	6	

3.2.3   Qualitative Assessment

This strategy requires an extensive data manipulation.

3.2.4   Procedure

The *road segment* shape file has a unique 15-digit identifier field [Index] consists of the segments' county, jurisdiction, etc. identification numbers. These identification numbers, on the other hand, are listed under separate fields in the *road string* shape file. To make these two files comparable a similar unique identifier field has to be created by concatenating the county, jurisdiction, etc. fields in the road string file. These new identifiers of the strings consist of 14 digits. Furthermore, the identifiers in the *road segment* file should also be modified, in which their sixth digits will be eliminated.

- Open a new View
- Click on Add Theme icon
- Select *road* shape file
- Highlight *road* theme by clicking on its text in the View
- Click on Open Theme Table icon

Add a new field in the *road* attributes table for the new 14-digit identifiers
- Click on Open Theme Table icon
- Click on Table/Start editing Menu
- Click on Edit/Add Field Menu
- Name the new field New_Index
- Select String for the field type
- Close the add-field window
- Select the [New_Index] field and click on Calculate icon
- Enter the following expression to create a 14-digit identifier for each record

  [Co].Asstring + [Jurisd].Asstring + [Sys].Asstring + [Stat].Asstring +

[Pre].Asstring + [Route].Asstring + [Seq].Asstring

- Click on Table/End editing Menu

Next, the sixth digits of the identifiers in the road segment shape file [Index] are eliminated.
- Click Add Theme icon
- Select *segment* shape file
- Highlight *segment* theme by clicking on its text in the View
- Click on Open Theme Table icon

Add a new field in the road segment attribute table for the new 14-digit index
- Click on Open Theme Table icon
- Click on Table/Start editing Menu
- Click on Edit/Add Field Menu
- Name the new field New_Index
- Select String for the field type
- Close the add-field window
- Select the [New_Index] field and click on Calculate icon
- Enter the following expression to create a 14-digit identifier for each record

[Index].left(5) + [Index].right(9)

- Click on Table/End editing Menu

Now both road string and road segment shape files include [New_Index] fields, which contain unique 14-digit identifiers. To determine whether or not a segment is a curve, it is assumed that if at least 50 percent of total number of accidents assigned the segment are on-curve accidents, the segment is then marked as a curve segment.

Spatial join the *segment* and *accident* attributes tables
- Click Add Theme icon
- Select *accident* shape file
- Highlight *accident* theme by clicking on its text in the View
- Click on Open Theme Table icon
- Click on [Shape] field of the *segment* attributes table
- Click on [Shape] field of the *accident* attributes table
- Click on Join icon

The *segment* attributes table closes. The new *accident* attributes table contains all related segment data for each accident record. Next, road string information will be added to the all-accident data.

Join the road and all-accident attribute tables
- Click on [New_Index] field of the *road* table
- Click on [New_Index] field of the *accident* table
- Click on Join icon

The *road* attributes table closes.   The new *accident* attributes table contains all related road as well as segment data for each accident record.

Select the accident records that are close to roadways. The majority of the records are within 0 to 0.007 range.
- Click on Query Builder icon
- Input the following expression in the dialog box

  [Distance] < 6.769

- Click on Theme Menu/Convert to Shapefile to create a new theme for the *accident* attributes table under *all-acc-seg* name

Select curve accidents, which are not occurred at intersections
- Highlight *all-acc-seg* theme by clicking on its text in the View
- Click on Query Builder icon
- Enter the following expression in the dialog box

  [Road_geometry] = 4 or [Road_geometry] = 5 or [Road_geometry] = 6 and [Int_class] = 0

Count the on-curve accidents on each segment
- While the on-curve accident records are highlighted in the active *all-acc-seg* attributes table, click on Menu/Xtools/Table Frequency
- Select [Seg_seq] and [Index] fields from the Select Frequency Field(s) dialog box and click OK
- Click OK in the Select Summary Field(s) dialog box without making any selection
- Save the new table as *brsegsum_curv*
- Rename the [Frequency] field to [curve_count] using Table/Properties/Alias Menu

Count the total number of accidents on each segment
- Click Select None icon while the *all-acc-seg* attributes table is active
- Click on Menu/Xtools/Table Frequency
- Select [Seg_seq] and [Index] fields from the Select Frequency Field(s) dialog box and click OK
- Click OK in the Select Summary Field(s) dialog box without making any selection
- Save the new table as *brsegsum*
- Rename the [Frequency] field to [all_count] using Table/Properties/Alias Menu

The reason for renaming the [Frequency] fields is to eliminate errors when calculating curve accident percentages.

Join *brsegsum* and *brsegsum_curv* tables with the *co_03_seg* shape file. Having both [all_count] and [curve_count] fields in a shape file enables us to calculate curve accident percentages and to show them on the map.

A unique identifier field needs to be created for each of these three tables to facilitate joining procedures. This field is the combination of [index] and [Seg_seq] fields.

- Click on Table/Start editing Menu
- Click on Edit/Add Field Menu
- Name the new field [Index_seg]
- Select String for the field type
- Close the add-field window
- Select the [Index_seg] field and click on the Calculate icon
- Enter the following expression ("++" symbol combines the two strings with a space between the two fields)

  [Index] ++ [Seg_seq]

- Click on Table/End editing Menu
- Join the *brsegsum* table and *co_03_seg* shape file by selecting the [Index_seg] fields when co_03_seg file is active
- Join the *brsegsum_curv* table and co_03-seg shape file by selecting the [Index_seg] fields when co_03_seg file is active

Both brsegsum and brsegsum_curv tables close. Now the co_03_seg attributes file includes the total as well as on-curve accidents for each segment.   Next, the curve accident percentages are determined for each segment.

- While the co_03_seg attributes table is open click on Table/Start editing Menu
- Click on Edit/Add field Menu
- Name the new field [%curve_acc]
- Click on Field/Calculate Menu
- Enter the following expression

$$1 - \frac{[all\_count] - [curve\_count]}{[all\_count]}$$

Next, the number of on-curve accidents and on-curve accident percentages are shown on the map.

- Click on Theme Menu/Convert to Shapefile to create a new theme for the *co_03_seg* attributes table under *on_curve_seg* name
- Add the *on_curve_seg* theme to a new View
- Double click on the *on_curve_seg* theme in the View to open Legend Editor
- Select Graduated Symbols from the Legend Type pull down menu
- Select [curve_count] for the Classification Field and click on Apply button

Repeat the above five steps for the on-curve accident percentages

- Click on Theme Menu/Convert to Shapefile to create a new theme for the *co_03_seg* attributes table under *percent_on_curve* name
- Add the *percent_on_curve* theme to the new View
- Double click on the *percent_on_curve* theme in the View to open Legend Editor
- Select Graduated Symbols from the Legend Type pull down menu

- Select [%curve acc] for the Classification Field and click on Apply button

3.2.5   <u>Illustration</u>
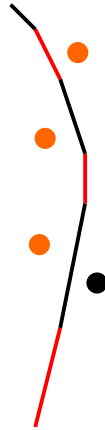
## 3.3 Bearing-Method I

3.3.1 Definition
The deflection angle of each segment with respect to its successive one is calculated using a Microsoft Excel spreadsheet. A segment is tagged as a curve when its deflection angle is either greater or equal than a selected value.

3.3.2 Quantitative Assessment
3.3.2.1 Type I Error
3.3.2.2 Type II Error
The accuracy level of the strategy was determined for the deflection angles of 1 to 15 degrees. As shown in the figure below, a 74 percent accuracy level (i.e., highest level) is observed at the 6° deflection angle when the Type I and Type II errors are 8 and 18 percent, respectively. However, if the concern is not to miss a curve when actually is a curve (i.e., Type II error), a segment should be tagged as a curve when its deflection angle is either greater or equal than 1° (or even less than 1° for a lower Type II error).
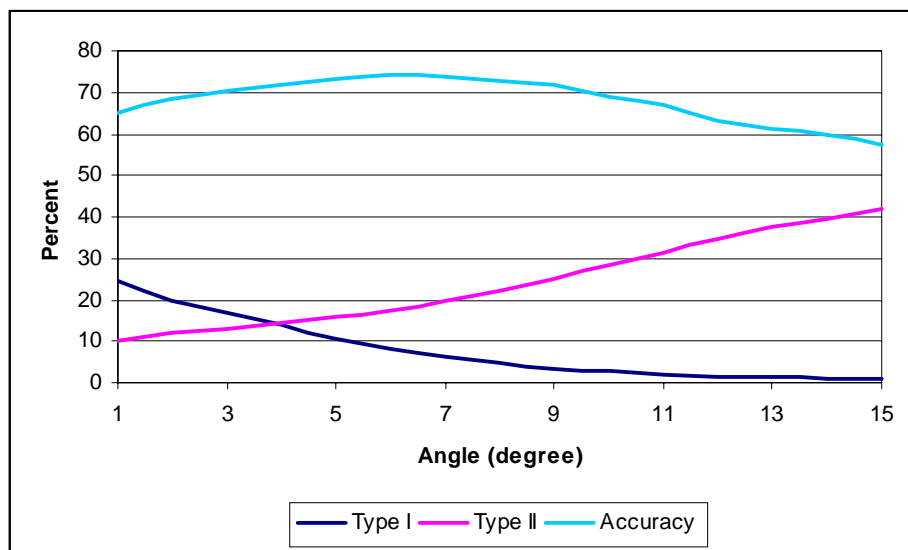
3.3.3 Cost

| | Manpower (days) | | | |
	Ali	Zach	Student	Amount ($)
Fix cost	1	4	5	
Marginal cost	1	1	2	

3.3.4 Qualitative Assessment
This strategy requires an extensive data manipulation.

3.3.5   Procedure

Provided an Excel spreadsheet containing segments' x-y coordinates, the angle that each
segment makes with its successive segment is calculated. Depending on the orientation of the
segments constituting the network, some of the values may be negative. However, since the
primary concern in this part of the analysis is the calculation of angles between the segments,
absolute values of the differences are considered.

Unique identifier	X	Y	Length (in miles)	Angle from Horizontal (in degrees) Equation 1	Direction	Difference in angle (in degrees)	Absolute difference in angle (in degrees)
313010000900103	285.03	224.65	0.68	1.70	NE	0.35	0.35
	285.91	224.68	0.00	2.05	NE	-0.17	0.17
	285.91	224.68	0.46	1.87	NE	0.00	0.00
313010000900203	285.91	224.68	0.46	1.87	NE	-1.06	1.06
	286.38	224.69	0.42	0.82	NE	0.01	0.01

It is assumed that any segment with the absolute angle of 5° (or 10° in another case) or greater is
considered as a curve. The accuracy of this strategy is measured by overlaying the study site's
maps on its aerial photos using GeoMedia.

- Open GeoMedia
- Create new Geo workspace
- Accept the default file name *normal.gwt*
- In Geo workspace 1, click on "Warehouse" on the Menu bar
- Click on New connection
- Accept the default Access option for the database type
- Accept the default Access Connection 1
- Select the site database (e.g., *allamakee.mdb*)
- Open the file as read only or read-write
- In Geo workspace 1, click on Analysis on the Menu bar
- Click on New Query
- Use Select Features in Access Contribution 1 and click on *CL_99* (This is the file that
  contains the road network data of Allamakee county.)
- In Filter, use RTE_INDICATOR=1 (This option will only load the major roads in the
  network.)
- In Geo workspace 1, click on "Analysis" on the Menu bar
- click on Join
- For the "left side of join", use Access Contribution 1 and *CL_99*
- For the "right side of join", use Access Contribution 1 and *BRCURVE* (This the file that
  contains the horizontal curves in the road network of Allamakee county.)
- For "available attributes" click on [Road link] on both the left side and the right side
- For the "type of join" select "right outer"
- For the display option check the box for "Map window" and uncheck the box for "Data
  window" (This will ensure that the network will be displayed only in the map window
  and not in the data window.)

Apply different color and weight to the join of *CL_99* and *BRCURVE* files.
- Right click on the *CL_99* and *BRCURVE* join in the legend window

- Click on Properties
- Click on Style and make necessary modifications

Next the aerial photos are inserted. The road network will be overlaid on the aerial photos.
- Click on Insert on the Menu bar
- Click on Image
- Select the site's aerial photos file (e.g., *Allamakee.doq; file type: tiff(*tiff)*)
- In the Geo workspace 1, double click on a link (string) of the road network to open an attribute table
- Identify the [unique identifier] of the string from the attribute table
- Based on the this [unique identifier] select the appropriate Excel file of the site study
- Close the attribute table and click on the string
- Use the Edit Geometry icon to bring up the points which make up the string
- With the assistance of the actual road network on the background, visually inspect whether the points are lying on curves or lines (see Figures 3 and 4)
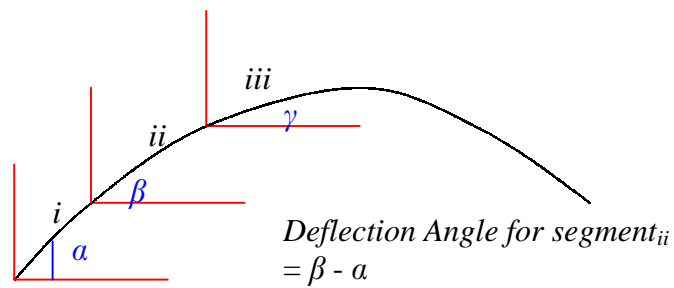- Adopt the same procedure for all the links in the network

Figure 3 Overlay of Network Maps and aerial photos – Exact Match

**Figure 4 Deviation of Network Maps from the aerial photos (in very rare cases)**

3.3.6   <u>Illustration</u>

Deflection Angle for segment$_{ii}$
= β - α

3.4   Bearing Method II

3.4.1   Definition

This is a comprehensive version of the Bearing-1 strategy. Using the Map Object and Visual Basic software, the deflection angles of each segment with respect to its following and leading ones as well as bearings and lengths of the segments are calculated.
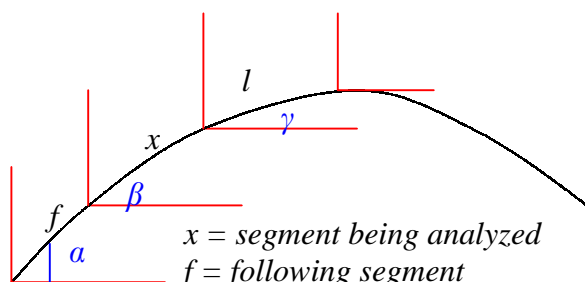
*x = segment being analyzed*
f = following segment
l = leading segment
Lengths of x, f, l segments = d_x, d_f, d_l
Bearings of x, f, l segments = α, β, γ
Deflection Angle of x segment with respect to following segment

The Bearing-2 strategy is also capable of identifying whether there are more than one leading segments (i.e., an intersection). In cases, where there are more than one leading segment (see figure below), a leading segment with a lowest deflection angle will be selected. For example, in the figure shown below, segment x has three leading segments (l_1, l_2, and l_3) in which it selects segment l_2.
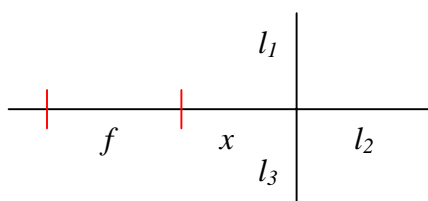
3.5 Manual Method (String- or Segment-based)

3.5.1   <u>Definition</u>
Roadways at a selected site study are marked as lines or curves by visually inspecting the maps in the GIS environment. The site was inspected by two individuals to facilitate the determination of Type I and Type II error percentages. The observations made by individual *A* were compared to the ones made by individual *B*, who was assumed to be correct. The Type I error percentage, for example, was determined by dividing the number of records that individual *A* mistakenly indicated as lines by the total number of observed records.

3.5.2   <u>Cost (string)</u>

	Manpower (days)			
	Ali	Zach	Student	Amount ($)
Fix cost	1	1	2	
Marginal cost	0.5	0.5	1	

3.5.3   <u>Cost (segment)</u>

	Manpower (days)			
	Ali	Zach	Student	Amount ($)
Fix cost	1	1	4	
Marginal cost	0.5	0.5	2	

3.5.4   <u>Qualitative Assessment</u>
This strategy may result in over estimation of horizontal curves' crash rates.
- An entire length of a designated string is considered as the curve length when only a section of the string is actually curved.

3.5.5   <u>Procedure</u>
- Open MapInfo
- Click on Table and Press Open
- Open the shape file (a map of the area will appear)
- Click on Window/New Browser
- Click on Query/SQL Select
- Enter the following statements for the segment file
  - Select the table
  - Enter ZCURVE_ACC>0 for Condition
  - Enter ZCURVE-ACC for Order by Columns
  - Enter a desired name for the new table for Tabled Named
- In addition to the proceeding statements, enter the following statements for the string file
  - Select the table
  - Enter ALL_Count >=1 And Curve_Count<=0 for Condition
  - Enter ZCURVE_ACC for Order by Columns
  - Enter a desired name for the new table for Tabled Named

- Close the Browser Window
- Manually inspect each individual queried record and mark whether or not it is a curve (*y* or *n*) in the appropriate field of the table

3.5.6 Illustration
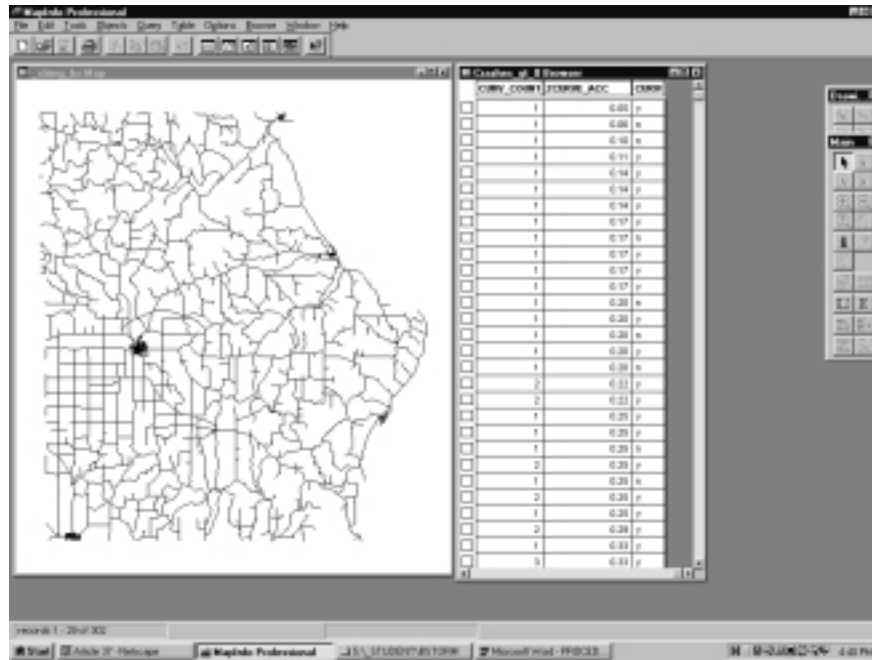
3.6   Vertex Method

3.6.1   Definition

A program was developed to "walk the line" of each base record string. As the program walks the line, it calculates the distance between vertices (i.e., segment distance). If a distance of 3/100th of a mile (~ 50 meters) or less is encountered the entire record (string) is flagged as a curve. The 3/100 value can be defined as deemed appropriate.
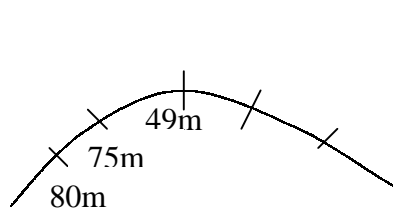
3.6.2   Cost

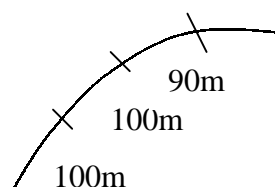|	Manpower (days)			Amount ($)
	Ali	Zach	Student	
Fix cost	1	1	2	
Marginal cost	0.5	0.5	1	

3.6.3   Qualitative Assessment

This strategy may result in over estimation of horizontal curves' crash rates.
- An entire length of a designated string is considered as the curve length when only a section of the string is actually curved.

3.6.4   Illustration

One segment < 50 m – A

All segments > 50 m – Not A

3.7 Length (String-based)

3.7.1 <u>Definition</u>
The actual length as well as end-to-end (straight line) lengths of a string is calculated using an Arcview user-code. A string is tagged as a curve when its weighed difference, calculated by the following equation, is greater than 5.

$$weighed\_difference = \frac{actual\_length - end\_to\_end\_length}{actual\_length} \times 1,000,000$$
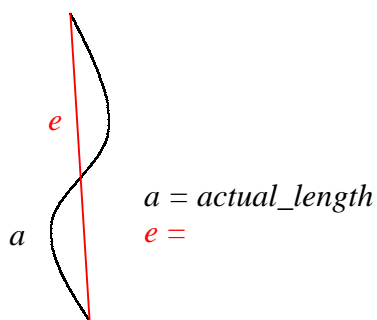
3.7.2 <u>Cost</u>

	Manpower (days)			
	Ali	Zach	Student	Amount ($)
Fix cost	1	1	2	
Marginal cost	0.5	0.5	1	

3.7.3 <u>Qualitative Assessment</u>
This strategy may result in over estimation of horizontal curves' crash rates.
- An entire length of a designated string is considered as the curve length when only a section of the string is actually curved.

3.7.4 <u>Illustration</u>

$a = actual\_length$
$e =$

3.8   Length (Segment-based)

3.8.1   Definition

The purpose of this strategy was to determine the impact of length and bearing of a segment in identification of curves. A statistical modeling of the bearing and length of the identified curves' segments reveals that a segment's length is the best predictor in identification of curves. The model indicates that as the segment's length increases, the likelihood of it belonging to a non-curve string increases.

3.8.2   Procedure

3.8.2.1   Data Manipulation

The bearings and lengths of four routes' segments in Allamakee County (see Figure 5) were determined through the use of the Bearing-1 strategy.   Before conducting the statistical modeling, the segments contained between the visually identified point of curvature (PC) and point of tangency (PT) of each curve were determined. Using the following procedure, the curves' segments contained between the points of curvature and tangency were identified.
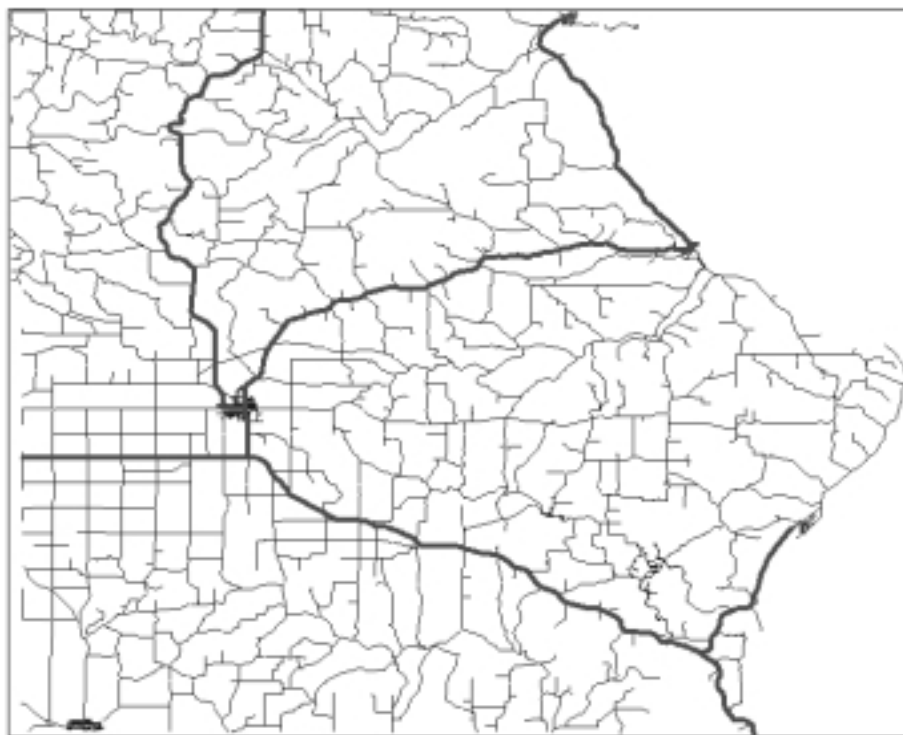

Figure 5 Selected Routes in Allamakee County

- Open the four Excel files containing the road network data of the four selected routes
- The 'Unique Identifier' field contains the unique identifiers for the selected road network's strings. Each string consists of one or more segments. The last digit of the unique identifier represents the number string's vertices. Thus, the number of string's segments represented by one minus the last digit of the unique identifier.

- Add a new field titled 'ID'
- Insert the first 15 digits of the unique identifier in the 'ID' field
- Add a new column titled 'SEG_SEQ' and manually enter the segment numbers for each unique identifier

Unique Identifier	ID	X	Y	SEG_SEQ
313010000900103	031301000090010	285.029820	224.650460	1
	031301000090010	**285.910390**	**224.676530**	2
		285.912070	**224.676590**	
313010000900203	031301000090020	285.912070	224.676590	1
	031301000090020	**286.375840**	**224.691770**	2
		286.795430	**224.697770**	
313010000900302	031301000090030	286.795430	224.697770	1
		286.882240	**224.699020**	

- Copy the ID, SEG_SEQ, CHAR, LENGTH, BEARING, DIRECTION, DIFF_ANGLE, ABS_DIFF_ANGLE fields into a new worksheet
- Perform a data sort on the ID field
- Delete all the rows with a blank ID
- Add a new field titled 'ID SEG_SEQ'
- Combine the ID and SEG_SEQ fields in the ID SEG_SEQ field using the Excel's CONCATENATE function

ID	SEG_SEQ	ID SEG_SEQ
031301000090010	1	031301000090010 1
031301000090010	2	031301000090010 2
031301000090020	1	031301000090020 1
031301000090020	2	031301000090020 2
031301000090030	1	031301000090030 1
031301000090040	1	031301000090040 1
031301000090050	1	031301000090050 1
031301000090060	1	031301000090060 1
031301000090070	1	031301000090070 1
031301000090080	1	031301000090080 1
031301000090080	2	031301000090080 2

- Perform the preceding steps for all four Excel files
- Copy the new worksheets into a new Excel file (bearing.xls)
- Convert the file to a dbf (bearing.dbf)
- Open a new view in ArcView
- Add the '%segment.shp' theme
- Open the attribute table of '%segment.shp'
- Add table 'bearing.dbf'
- Join the '%segment.dbf' and 'bearing.dbf' tables using 'Index' as the common field
- Query for road network's segments in Allamakee County (ID = "03*")
- Convert selected data set to a shape file (bearing2.shp)

- Add it as a new theme
- Open the attribute table of the 'Bearing2.shp'
- Add two new fields titled 'Location' and 'Curve_No'
- Insert the visually identified point of curvature (PC) and point of tangency (PT) for each curve in the 'Location' field
- Enter identical numbers for the segments contained between the PC and PT in the 'Curve_No' field. The contained segments and the segments marked as PC and PT are identified as segments of a curve (identified by 1 in the 'Curve' field).

INDEX_SEG	CURVE	DIFF_ANGLE	ADIFF_ANGLE	LENGTH	LOCATION	CURVE_NO
031301000090820 1	1	12.13	12.13	145.152	PC	37
031301000090820 2	1	16.77	16.77	237.952	PT, (PC)	37, (38)
031301000090820 3	1	16.11	16.11	119.552		38
031301000090820 4	1	-27.66	27.66	174.651	PT, (PC)	38, (39)
031301000090820 5	1	8.89	8.89	149.850		39
031301000090820 6	1	0.00	0.00	88.819		39
031301000090830 1	1	9.17	9.17	140.270	PT	39
031301000090830 2	0	-0.01	0.01	20.513		0
031301000090835 1	0	0.77	0.77	180.866		0
031301000090837 1	0	-1.00	1.00	42.529		0
031301000090840 1	0	0.24	0.24	138.358		0
031301000090845 1	0	0.00	0.00	60.299		0
031301000090850 1	0	0.00	0.00	50.236		0
031301000090860 1	0	21.80	21.80	211.796		0
031301000090860 2	1	92.05	92.05	87.710	PC	40
031301000090870 1	1	0.01	0.01	182.848		40
031301000090880 1	1	89.60	89.60	100.511	PT	40

3.8.2.2 Statistical Modeling

Of 872 segments observed on the selected routes, 610 were identified as curve segments. The remaining 262 segments were classified as straight segments. Summary statistics for both types of segments are presented in Table 1. Figures 5 and 7 present segment length histograms for segments that were identified to be portions of curves and straight strings, respec tively.

Table 1 Summary Statistics For Segment Length

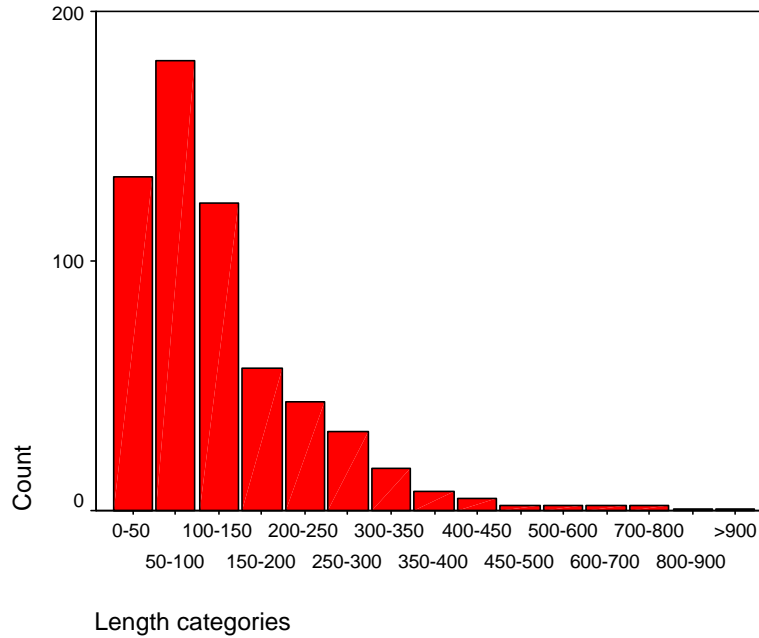|		CURVE	STRAIGHT
Segment Count		610	262
Mean Length (m)		127.76	212.99
Minimum Length (m)		0.02	0.72
Maximum Length (m)		1381.12	1620.70
Percentiles	95	327.77	692.02
	99	603.47	1454.02

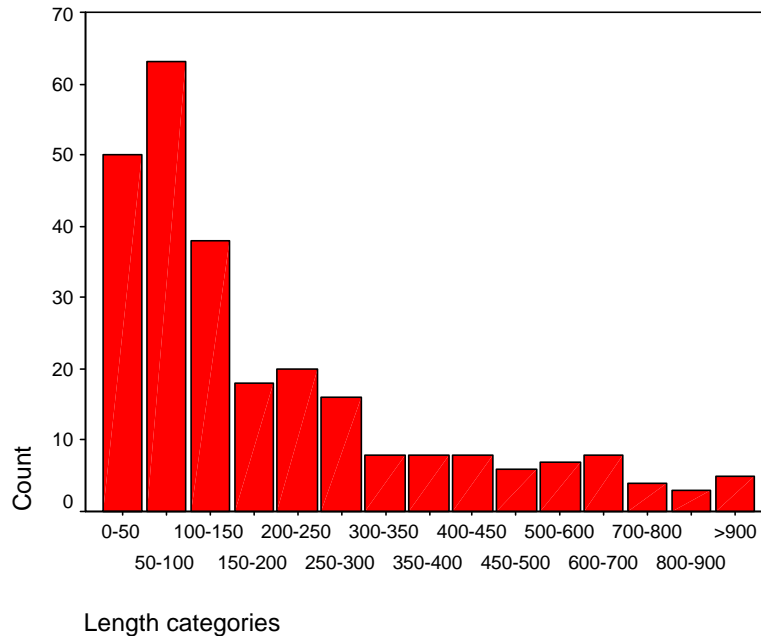**Figure 6 Histogram of Curve Segment Length**

Figure 7 Histogram of Straight Segment Length

Information on length (measured in meters) and the change in deflection angle (both observed and absolute, measured in degrees) for each segment was collected. The research team adopted a statistical approach to determine if segment length and deflection angle contributed to the fact that a particular segment was part of a curve or straight string. The information that a segment was part of a curve or straight section was coded as (0,1), where 0 indicated that a segment was part of a curve and 1 indicated otherwise. This variable served as the dependent variable in this analysis. The independent variables were segment length, deflection angle, and absolute value of deflection angle.

The binary probit modeling technique was used to observe the effect of independent variables on the dependent variable. This procedure measures the relationship between the strength of a stimulus and the proportion of cases exhibiting a certain response to the stimulus. This modeling technique is most useful for situations where the dependent variable is dichotomous (as in this case).

The probit model (see Table 2) indicated that the best predictor of a segment belonging to a curve or a straight section was its length. The deflection angle and absolute value of deflection angle indicated minimal predictive power and were thus removed from the model's specification. The model indicates that as the length of a segment increases, the likelihood of it belonging to a straight section increases. Thus, as expected, longer lengths of segments are associated with straight sections. The marginal values indicate the change in the dependent variable due to a unit (meter) change in the independent variable beyond its mean value. Therefore, a unit change in the length of the segment beyond its mean value (i.e., from 153.37 to 154.37 m) increases the chance of that segment being a straight section by 0.06 percent (0.00060).

Table 2 Binary Probit Model

(Dependent variable: segment is part of a straight section = 1 or part of a curve = 0)

Variable	Coefficient	Std Error	t-statistic	Mean of X	Marginal value
Constant	-0.276	0.177	-15.63	-	-
Length (m)	0.602	0.992	6.06	153.37	0.00060

```
Model statistics

Log likelihood function        -511.7014
Restricted log likelihood      -533.0122
Chi-squared                     42.62147
Degrees of freedom                     1
Significance level              0.000000
Percent correctly predicted        72.48
```

3.9 Length-based (Defined Interval)

3.9.1   Definition
The actual length and end-to-end (straight line) lengths of a selected interval along a string will be calculated using an Arcview user-code. An interval will be marked as a curve when the actual and end-to-end lengths of the defined interval differ by a selected threshold value. An advantage of this strategy with respect to the "length (string)" technique, is its capability to determine the beginning and the end points of a curve.

3.9.2   Illustration
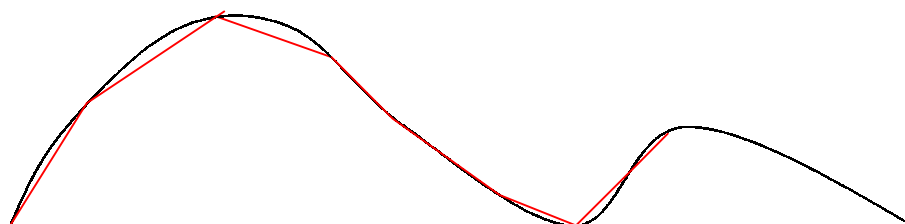
4   Curve Identification Strategies Qualitative Assessment

Table 3 Developed and Examined Strategies to Identify Horizontal Curves

Strategies	Quantitative Assessment (%)	Type I Error (%)	Type II Error (%)
Crash (string)	66	23	11
Crash (segment)	68	30	2
Bearing-1		See Figure 8[*]	
Bearing-2		No Assessment	
Manual (string)	85	13	2
Manual (segment)	72	28	0
Vertex	51	0	49
Length (string)	80	19	1
Length (segment)[**]		No Assessment	
Length (defined interval)		No Assessment	

[*] The accuracy level of the strategy was determined for the deflection angles of 1 to 15 degrees. As shown in Figure 8, a 74 percent accuracy level (i.e., highest level) is observed at the 6° deflection angle when the Type I and Type II errors are 8 and 18 percent, respectively. However, if the concern is not to miss a curve when actually is a curve (i.e., Type II error), a segment should be tagged as a curve when its deflection angle is either greater or equal than 1° (or even less than 1° for a lower Type II error).

[**] The purpose of this strategy was to determine the impact of length and bearing of a segment in identification of curves. A statistical modeling of the bearing and length of

the identified curves' segments reveals that a segment's length is the best predictor in identification of curves. The model indicates that as the segment's length increases, the likelihood of it belonging to a non-curve string increases. The data manipulation and statistical modeling of this strategy is included in Appendix B.
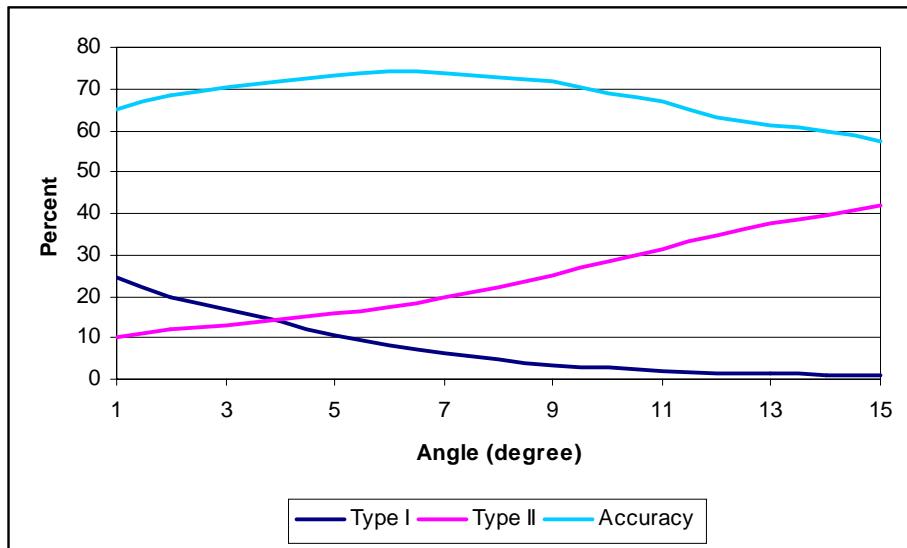

Figure 8 Quantitative Assessment of Bearing-1 Strategy

Appendix C
Horizontal Curve Identification Methodology

1 Curve Identification Technique I

Once the curves' segments have been identified, using the available data sources, the following steps are conducted to calculate curves' radii and degrees:

1. Eliminate the mistakenly selected segments as curves through visual inspections
2. Manually put boxes around curves
3. Perform clipping
    i. Assign a unique number to each polygon
    ii. Assign the polygon unique numbers to the curves
    iii. Calculate the length of a curve's segments
    iv. Calculate weighed AADT
4. Combine the clipped segments
5. Calculate chord and curve lengths
6. Calculate the curves' radii

1.1 Identify Errors

The first two main steps are performed manually. In the first step, all selected segments are inspected for possible errors. The mistakenly selected segments are eliminated and boxes are put around the remaining curves using the following procedure:

1.2 Draw Boxes Around Curves

- Open a new view in ArcView
- Add the theme "Co85_prisec.shp"
- Open the attribute table of "Co85_prisec.shp"
- Query the table to identify road strings with advisory speed limit signs, which are the indications of presence of curves.
- Add a new theme named "Polygon.shp"
- Click on Theme on the menu bar
- Click on Start Editing
- Draw polygons around the identified curves. Each polygon encompasses segments of a curve from its points of tangency and curvature.

1.3 Perform Clipping

The purpose of the "clipping" is to isolate the boxes, with their curves within, from the rest of the road network.

- Open a new view in ArcView
- Add the following themes:
  - Polygon.shp - This theme contains the polygons that define the curves in the road network of the county.
  - Co85_prisec.shp - This theme contains the network of primary and secondary roads in the county
- Select both themes
  - Click on "Edit" on the menu bar
  - Click on "Copy Themes"
  - Click on "Paste"
- Rename "Polygon.shp" and "Co85_prisec.shp" to "Polygon_box.shp" and "Co85_prisec_2.shp"
- Delete the original themes
- Click on project window
  - Click on "File" on the menu bar
  - Click on "Extensions"
  - Click on "Geoprocessing"
- Arrange the themes in the view window such that "Co85_prisec_2.shp" is on top
- Click on the view window
  - Select all the features of "Polygon_box.shp"
  - Click on "View" on the menu bar
  - Click on "Geoprocessing Wizard"
  - Select the option "Clip one theme based on another"
  - Click on "Next"
  - Select "Co85_prisec_2.shp" as the input theme to clip
  - Select "Polygon_box.shp" as the polygon overlay theme
  - Specify the location of the output file (e.g., clip2.shp)
  - Click on "Finish"

Before combining the curve segments inside each polygon, the following steps need to be carried out:

1.3.1   Assign a unique number to each polygon

A unique value is assigned to each polygon. This is an indirect way of numbering the curves' segments inside the polygon. The following Areview Avenue Script is used to assign numbers to polygons:

```
thisProject=av.GetProject
thisView=thisProject.FindDoc("View1")
themesList=thisView.GetThemes
select theme=MsgBox.ListAsString(themesList,"Themes","Please select")
selectTab=selecttheme.getFTab
selectTab.seteditable(true)
autofield=field.make("Id",#field_decimal,10,0)
selectTab.addfields({autofield})
autofield.seteditable(true)
for each i in selectTab
Id=i+1
SelectTab.setvalue(autofield,i,Id)
end
```

| SHAPE	POLYGON_ID
Polygon	1
Polygon	2
Polygon	3
Polygon	4
Polygon	5
Polygon	6
Polygon	7
Polygon	8
Polygon	9
Polygon	10
Polygon	11
Polygon	12
Polygon	13
Polygon	14
Polygon	15

1.3.2   Assign the polygon unique numbers to the curves

In this step the polygons' unique numbers are assigned to their associated curve's segments. This would enable us to integrate the curves' segments based on their unique assigned identification numbers. The "assign data by location" option of the Geoprocessing Wizard is used to spatial join the data from the attribute table of curves theme to the attribute table of "clipped" roads theme.

- Use the curves theme (polygon theme) as the source table and the "clipped" roads theme (line theme) as the destination table
- Click on "View" on the menu bar
- Click on "Geoprocessing Wizard"
- Select the option "assign data by location"
- Click on "Next"
- Select "Clip2.shp" as the theme to be assigned data to
- Select "Polygon_box.shp" as the theme to assign data from
- Click on "Finish"

1.3.3   Calculate the length of a curve's segments

A curve length is determined by adding the segments that form the curve inside a box. For those segments that their entire lengths are not included in the box only their partial lengths are considered in calculating the curve length. For example, the selected curve (see the figure below) consists of segments, however, the actual curve length is the only length inside the box.   Using the following procedure determines the segments' lengths that are inside the box. This process would eliminate the over representation of curve lengths.
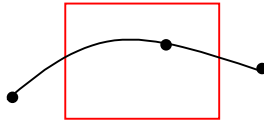
- Open the attribute table of "Clip2.shp"
- Click on "Table" on the menu bar
- Click on "Start Editing"
- Click on "Edit"
- Click on "Add Field"
- Name the field as "New_length"
- Click on "New_length"
- Click on "Field" on the menu bar
- Click on "Calculate"
- [New_length] = [Shape]. RunLength
- The new length values are in feet.

1.3.4   Calculate weighted AADT

There are two possible ways to determine a curve AADT (average annual daily traffic). We can simply use the average all segments' AADT that form a curve or more accurately use portions of AADT's of those segments that are partially inside the box. Using the following procedure a curve AADT is determined by weighing the degree of participation of a segment in forming a curve.

- Open the attribute table of "Clip2.shp"
- Click on the field "Polygon_id"
- Click on "Field" on the menu bar
- Click on "Summarize"
- The field is "New_Length"
- Summarize by sum
- Save the summary table to the required location (i.e., Sum_New_length.dbf)
- Using the [Polygon_id] as a common field, join the Sum_New_length.dbf and the attribute table of "Clip2.shp"
- The destination table is the attribute table of "Clip2.shp"
- Click on "Edit"
- Click on "Add Field"
- Name the field as [Weighted_Aadt]
- Click on "Field" on the menu bar
- Click on "Calculate"
- Enter $[Weighted\_Aadt] = \left[\dfrac{[\text{New\_length}]}{[\text{Sum\_length}]} \right] \times [\text{Aadt}]$

AADT	NEW_LENGTH	POLYGON_ID	SUM_NEW_LENGTH	WEIGHTED_AADT
1100	263.411	6	432.9690	669
1100	169.558	6	432.9690	431
80	67.095	1	129.0660	42
80	61.971	1	129.0660	38
25	347.908	2	347.9080	25
25	116.539	3	290.9110	10
25	174.372	3	290.9110	15
25	21.303	5	223.4310	2
25	108.383	5	223.4310	12
25	93.089	4	197.0410	12
25	93.745	5	223.4310	10
25	103.952	4	197.0410	13

1.4   Combining the Clipped Segments

The next step is to combine the boxed curves' segments to create polylines.

- Click on "View" on the menu bar
- Click on "Geoprocessing Wizard"
- Select the option "Dissolve features based on an attribute"
- Click on "Next"
- Select "Clip2.shp" as the theme to dissolve
- Select "Polygon_id" as the attribute to dissolve
- Specify the output file location (e.g, Dissolve1.shp)
- Click on "Next"
- For the additional fields to be included in the output file choose:
- New_length by sum
- Weighted_Aadt by sum
- Index by First
- Index by Last
- Click on "Finish"

1.5   Calculate chord and curve lengths

The length and chord length of a curve calculation will be enable us to determine the curves' radii. The lengths can be calculated using an ArcView Avenue Script.

```
thisProject=av.GetProject
thisView=thisProject.FindDoc("View1")
themesList=thisView.GetThemes
select theme=MsgBox.ListAsString(themesList,"Themes","Please select")
selectTab=selecttheme.getFTab
selectTab.seteditable(true)
chLengthField=field.make("Chord_length",#field_decimal,10,4)
```

```
selectTab.addfields({chLengthField})
chLengthField.seteditable(true)
for each r in selectTab
segmentPolyLine=selectTab.ReturnValue(selectTab.FindField("Shape"),r)
segmentLine=segmentPolyLine.AsLine
segmentStartPoint=segmentLine.ReturnStart
segmentEndPoint=segmentLine.ReturnEnd
Chord_length=segmentStartPoint.Distance(segmentEndPoint)
selectTab.setvalue(chLengthField,r,Chord_length)
end
```

POLYGON_ID	COUNT	FIRST_INDEX	WEIGHTED_AADT	CHORD_LENGTH	CURVE_LENGTH
1	2	856502085230603	79.0000	126.2407	129.0660
2	1	856502085230710	78.0000	347.9076	347.9080
3	2	856502085230710	67.0000	287.6124	290.9110
4	2	856502085231806	17.0000	195.9667	197.0410
5	3	856502085231806	4.0000	217.5339	223.4310
6	2	856402085241312	1462.0000	430.1336	432.9690
7	2	856402085241312	882.0000	439.8060	442.9150
8	1	856502085231602	10.0000	139.2522	139.2520

1.6 Calculate the Curves' Radii

This step was described in the text.

1.6.1   Roadware Data

In cases where Roadware data are available, a new ArcView Roadware Theme is generated to convert divided roadways into single routes to prevent double counting of the clipped segment lengths.

- Open the project "Clip.apr"
- Add a new view and name it "Id Using Roadware"
- Add the theme "Roadware85.shp"
- Open the attribute table of "Roadware85.shp"
- The Roadware network consists of bi-directional routes for divided roadways. They are represented as direction 5 and direction 6. Only a small number of locations are represented by direction 6, thus, direction 6 is selected for the elimination.
    - Query the attribute table for route 5 by setting [Dir1] = 5
    - Convert the selected set to a shapefile
        - Click on Theme on the menu bar
        - Click on "Convert to a shapefile"
        - Name the shapefile as "New_Roadware.shp"
- Open the attribute table of "New_Roadware.shp"
- Add the theme "Polygon_box.shp"
- Open the attribute table

The clipping procedure, using the Roadware data, somewhat similar to the clipping of segments in cartography files.

- Open the attribute table of "Polygon_box.shp"
- Perform query by setting [Dfbearing] >=1 or [Dtbearing] >=1 to identify curves
- Start GeoProcessing
  - Click on project window
  - Click on "File" on the menu bar
  - Click on "Extensions"
  - Click on "GeoProcessing"
- Arrange the themes in the new window such that "New_Roadware.shp" is on top
- Click on the view window
  - Select all the features of "Roadware_box.shp"
  - Click on "View" on the menu bar
  - Click on "GeoProcessing Wizard"
  - Select the option "Clip one theme based on another"
  - Click on "Next"
  - Select "New_Roadware.shp" as the input theme to clip
  - Select "Roadware_box.shp" as the polygon overlay theme
  - Specify the location of the output file with the file name (e.g., clip3.shp)
  - Click on "Finish"

Using the following procedure, the weighted AADT calculated through the use of cartography files, is incorporated into the roadway data.

- Open the attribute tables of "Dissolve3.shp" and "Final_Dissolve_Rw.shp"
- Use the [Polygon_id] as a common field to join the two attribute tables
- Hide all fields in "Dissolve3.shp" except [Polygon_id] and [Weighted_Aadt]
- The destination table would be the attribute table of "Final_Dissolve_Rw.shp"

2 Curve Identification Technique II

2.1 Identify All Crashes Reported as Occurring on a Curve

- Select all primary road crashes, reported by the officer in the field as occurring on a curve.

([Road_class]<=2) and (([Road_geome]=4) or ([Road_geome]=5) or ([Road_geome]=6))

Note: This selection set limits the primary roadways evaluated by identifying potential problem curves or continuous adjacent curves.

2.2 Assign "Curve" Crashes to Roadway Centerline

- Using the [Shape] field, spatially join roadway centerline segments to the selected "curve" crashes.

- Summarize the joined table using the [Road_link] (unique Base Record segment identifier). This yields a table containing a [Road_link] value and corresponding number of crashes occurring on the roadway segment, [Count].
- Join the summary table, using [Road_link], to the roadway centerline theme.

2.3 Identify Curves and/or Curve Influence Areas

- Visually inspect, systematically, each potential curve site. For example, this may be accomplished by sorting the summary table by [Count] or [Co].
- Select the first record in the list and fit in the "View" window.
- While displaying both the "curve" crashes and roadway centerline themes, place polygons around isolated curves, consecutive curves, and curve influence areas.

Note:
- Given that crashes occurring on a curve often do not fall exactly on its cartographic representation, polygons are drawn in a manner as to include the crashes that should fall along this alignment.
- If an intersection occurs along a curve, a portion of the intersection road may be included in the polygon.

The remaining steps, beginning with "perform clipping", are essentially the same as curve identification technique - version 1, with two primary exceptions:

- A spatial join between the curve polygons and crashes is utilized to assign a polygon identifier to each crash feature. Use of the polygon features, instead of linear curve features, was deemed appropriate given the likelihood of crashes not falling along the cartographic representation of the curve. Since the polygon identifier and curve identifier are the same for a given location, the ID value may still be used to assign and summarize crash data to the respective curves.
- Crash rates, and rankings, are performed both with and without intersection crashes. Crashes are not limited to those defined as crashes having occurred on a curve.

**Appendix D
Procedures**

**Statewide Horizontal Curves With High Crash
Occurrences**

Statewide Fixed-object Crash Locations

Intersection Crashes along Rural Four-Lane Expressways

**Centerline Crossing Head-on Crash Locations on Rural
Two-Lane Paved Road**

**Four-Lane Undivided Corridors with High Crash
Occurrences**

1 Statewide Horizontal Curves (Using Roadware® Data)

1.1 Draw Polygons around Curves

1.1.1 Objective
- To identify curves on the primary road network of the State of Iowa.

1.1.2 Process
- Open a new view in Arc View by creating a new project "latest_curves.apr"
  - Add the theme "Rw00_pri_utm.shp" (This theme contains the roadware data for year 2000)
  - Add the theme "Rw99_pri_utm.shp" (This theme contains the roadware data for year 1999)
  - Add the theme "Rw98_pri_utm.shp" (This theme contains the roadware data for year 1998)
  - Add the theme "Tenyearcrashes_89-98.shp" (This theme contains the crashes that occurred on the road network of the state of Iowa from 1989 through 1998)
- Query "Tenyearcrashes_89-98.shp" for primary, non-intersection crashes (The query is: Road_class = 1 or Road_class = 2 and Int_class = 0). Save the selected set of crash records as "Pri_nonint_89-98.shp"
- Create a new polygon theme named "Rdware_polygon.shp" and create a new line theme named "Rdware_digi_curve.shp"
- Query "Rw00_pri_utm.shp" and "Rw99_pri_utm.shp" for Dfbearing > 1 (This will select only those road segments which have a bearing greater than 1 with the succeeding segment). This query helps for relatively easy identification of curves.
- In case of continuous roadware data, visually identify curves on the roadware data and draw polygons around the curves by editing the theme 'Rdware_polygon.shp'. Draw the polygons in such a way that the crashes occurring on curves are within the polygons. Also, draw the polygons in such a way that the primary road network ('primary_road.shp') closest to the potential curves on the roadware, falls within the polygons. Draw polygons only from the point of curvature (PC) to the point of tangency (PT) of the curves. Do not include right angle turns as curves.
- When roadware data is not continuous, manually digitize curves by editing the theme "Rdware_digi_curve.shp".
- Add a column to the attribute tables of both "Rdware_polygon.shp" and "Rdware_digi_curve.shp" to indicate whether the identified curve is a single curve or a set of multiple curves (if applicable).
- Create a new polygon theme and name it as "Digicurve_polygon.shp". Draw polygons around the manually digitized curves of "Rdware_digi_curve.shp" by editing the theme "Digicurve_polygon.shp".

1.2 Clip Road Network with Polygons

1.2.1 Objective
To isolate curves from the road network

1.2.2   Process
- Using Geo processing wizard, clip the primary road network ("primary_road.shp") with roadware polygons ("Rdware_polygon.shp"). Name the clipped theme as "Rdware_carto_clip.shp". Join the table "aadt_laneleng.dbf" to the attribute table of "Rdware_carto_clip.shp". The objective of clipping and joining is to associate Aadt values to the roadware curves in the roadware polygons.
- Using Geo processing wizard, clip the primary road network ("primary_road.shp") with roadware polygons ("Digicurve_polygon.shp"). Name the clipped theme as "manual_carto_clip.shp". Join the table 'aadt_laneleng.dbf' to the attribute table of "manual_carto_clip.shp". The objective of clipping and joining is to associate Aadt values to the manually digitized roadware curves.

1.3   Assign Unique Value to each Polygon

1.3.1   Objective

To be able to identify each polygon with a unique number

1.3.2   Why

To be able to indirectly assign unique numbers to all the curves. A segment or sets of segments contained in one polygon and constituting a curve get the same unique id as the polygon.

1.3.3   Process

- Run the following Avenue Script on "Rdware_polygon.shp" and "Rdware_digi_curve.shp" to assign unique values to all the polygons

```
thisProject=av.GetProject
thisView=thisProject.FindDoc("View1")
themesList=thisView.GetThemes
selecttheme=MsgBox.ListAsString(themesList,"Themes","Please select")
selectTab=selecttheme.getFTab
selectTab.seteditable(true)
autofield=field.make("Id",#field_double,10,0)
selectTab.addfields({autofield})
autofield.seteditable(true)
for each i in selectTab
Id=i+1
SelectTab.setvalue(autofield,i,Id)
End
```

1.4   Assign Polygon Ids to Cartographic Curves

1.4.1   Objective

To assign unique polygon id to each of the cartographic curve segments

1.4.2   Why

All the curve segments would be associated with a polygon id corresponding to the polygon they belong to. This would help in integration of all the curve segments based on the unique id assigned to them.

Process

Using the assign data by location option in Geo processing wizard, assign polygon ids to curves. First, assign data to "Rdware_carto_clip.shp" from "Rdware_polygon.shp" and then assign data to "manual_carto_clip.shp" from "Digicurve_polygon.shp".

1.5 Calculate Length of Cartographic Curve Segments

1.5.1 <u>Objective</u>

To calculate segment lengths for all cartographic curves.

1.5.2 <u>Why</u>

Some of the curves consist of two or more road segments. In some of these curves, the entire length of the segment is not a part of the curve. Hence, the length of such road segments is essential in order to eliminate the over representation of curve length.

1.5.3 <u>Process</u>

- Calculate the length of each segment of the curve using the function:
  Segment length = [Shape]. ReturnLength. Calculate segment lengths for both "Rdware_carto_clip.shp" and "manual_carto_clip.shp". The segment length values are in meters.

1.6 Calculate Weighted AADT for Cartographic Curves

1.6.1 <u>Objective</u>

To calculate the weighted Average Annual Daily Traffic(AADT) of each road segment of every cartographic curve.

1.6.2 <u>Why</u>

The given Aadt of each road segment is for the entire segment. But, the lengths of some of the segments constituting the curves are less than their original lengths. This is due to the fact that not all segments have their total lengths as part of the curve. Hence, the original Aadt cannot be applied for calculation of the total Aadt of the curve. The weighted Aadt is more appropriate.

1.6.3 Process

- In order to calculate the weighted Aadt of each segment, first calculate the total length of each curve by summarizing the attribute tables of "Rdware_carto_clip.shp" and "manual_carto_clip.shp" on Polygon Id with Segment Length as the summary attribute. Name the summary table of "Rdware_carto_clip.shp" as "Rdware_sum_newlength.dbf" and the summary table of "manual_carto_clip.shp" as "Manual_sum_newlength.dbf".
- Join "Rdware_sum_newlength.dbf" to the attribute table of "Rdware_carto_clip.shp" using Polygon Id. Similarly join "Manual_sum_newlength.dbf" to the attribute table of "manual_carto_clip.shp".
- Calculate the weighted Aadt of each of the segments using the formula:

$$\text{Weighted Aadt} = \left[\frac{\text{Segment length}}{\text{Total length}} \right] \times [\text{Aadt}]$$

1.7   Clip Roadware Data Network with Polygons

1.7.1   <u>Objective</u>

To isolate roadware curves from the roadware data network.

1.7.2   <u>Process</u>

- Using Geo processing wizard, clip the roadware data network ("Rw00_pri_utm.shp") with roadware polygons ("Rdware_polygon.shp"). Name the clipped theme as "Rw00_curve_clip.shp". Similarly clip the roadware data network ("Rw99_pri_utm.shp") with roadware polygons ("Rdware_polygon.shp"). Name the clipped theme as "Rw99_curve_clip.shp".

1.8   Assign Polygon Ids to Polygon Based Roadware Curves

1.8.1   <u>Objective</u>

To assign unique polygon id to each of the polygon based roadware curve segments.

1.8.2   <u>Why</u>

All the curve segments would be associated with a polygon id corresponding to the polygon they belong to. This would help in integration of all the curve segments based on the unique id assigned to them.

1.8.3   <u>Process</u>

- Using the assign data by location option in Geo processing wizard, assign polygon ids to roadware curves. First, assign data to "Rw00_curve_clip.shp" from "Rdware_polygon.shp" and then assign data to "Rw99_curve_clip.shp" from "Rdware_polygon.shp ".

- Some polygon ids could be common between "Rw00_curve_clip.shp" and "Rw99_curve_clip.shp" because of the overlap of the roadware data network of 2000 ("Rw00_pri_utm.shp") and the roadware network of 1999 ("Rw99_pri_utm.shp"). In order to eliminate the common polygon ids, first calculate the count of polygons by summarizing the attribute tables of "Rdware00_curve_clip.shp" and "Rdware99_curve_clip.shp" on Polygon Id. Name the summary table of "Rdware00_curve_clip.shp" as "Summary_00_clip.dbf" and the summary table of "Rdware99 _curve_clip.shp" as "Summary_99_clip.dbf". Then, join "Summary_00_clip.dbf" and "Summary_99_clip.dbf" to the attribute table of "Rdware00_curve_clip.shp" based on polygon id. Finally, query the attribute table of "Rdware00_curve_clip.shp" as follows: Count00 > 0 and Count99 > 0. The selected records are the common polygon ids. Delete the selected records.

1.9   Assign Polygon Ids to Manual Roadware Curves

1.9.1   <u>Objective</u>

To assign unique polygon id to each of the manual roadware curve segments.

1.9.2   <u>Why</u>

All the curve segments would be associated with a polygon id corresponding to the polygon they belong to. This would help in integration of all the curve segments based on the unique id assigned to them.

1.9.3   Process

- Using the assign data by location option in Geo processing wizard, assign polygon ids to manual roadware curves. Assign data to "Roadware_digi_curve.shp" from "Digicurve_polygon.shp".

1.10 Calculate Weighted AADT for Roadware Curves

1.10.1 Objective

To calculate the weighted Average Annual Daily Traffic (AADT) of each road segment of every roadware curve.

1.10.2 Why

The given Aadt of each road segment is for the entire segment. But, the lengths of some of the segments constituting the curves are less than their original lengths. This is due to the fact that not all segments have their total lengths as part of the curve. Hence, the original Aadt cannot be applied for calculation of the total Aadt of the curve. The weighted Aadt is more appropriate.

1.10.3 Process

- In order to calculate the weighted Aadt of each segment, convert "Rdware_carto_clip.shp" to "Rdware_wtd_aadt.shp" and "manual_carto_clip.shp" to "manual_wtd_aadt shp". Then, join the attribute table of "Rdware_wtd_aadt.shp" to "Rw00_curve_clip.shp", the attribute table of "Rdware_wtd_aadt.shp" to "Rw99_curve_clip.shp", and the attribute table of "manual_wtd_aadt.shp" to "Rdware_digi_curve.shp".

1.11 Dissolve Roadware Curve Segments

1.11.1 Objective

To integrate the road segments of every curve.

1.11.2 Why

Every curve could be made up of two or more road links. In order to represent the curve as one individual road segment, the dissolve is essential.

1.11.3 Process

- Using the dissolve features option in Geo processing wizard, dissolve the roadware curves. First, dissolve "Rdware_digi_curve.shp" based on polygon id and add weighted Aadt by sum and name it "Manual_dissolve.shp". Similarly, dissolve "Rw00_curve_clip.shp" and name it "Rdware00_dissolve.shp". Also, dissolve "Rw99_curve_clip.shp" and name it "Rdware99_dissolve.shp".

1.12 Calculate Length of Roadware Curve Segments

1.12.1 Objective

To calculate curve lengths for all roadware curves.

1.12.2 Process

- Calculate the length of each curve using the function:

Curve length = [Shape]. ReturnLength. Calculate curve lengths for "Manual_dissolve.shp", "Rdware00_dissolve.shp", and "Rdware99_dissolve.shp". The curve length values are in meters.

- If weighted Aadt is zero for any of the curves, perform a visual inspection of those curves and replace zero Aadt value with the Aadt of the nearest primary road segment.

1.13 Calculate Chord Length for Roadware Curves

1.13.1 <u>Objective</u>
To calculate the chord length of each roadware curve.

1.13.2 <u>Why</u>
Once the length and chord length of a curve are calculated, the radius of curvature could be calculated and hence the chord length is essential.

1.13.3 <u>Process</u>
- Run the following Avenue Script on "Manual_dissolve.shp", "Rdware00_dissolve.shp", and "Rdware99_dissolve.shp" to calculate the chord length of each curve

```
thisProject=av.GetProject
thisView=thisProject.FindDoc("View1")
themesList=thisView.GetThemes
selecttheme=MsgBox.ListAsString(themesList,"Themes","Please select")
selectTab=selecttheme.getFTab
selectTab.seteditable(true)
chLengthField=field.make("Chord_length",#field_double,10,4)
selectTab.addfields({chLengthField})
chLengthField.seteditable(true)
for each r in selectTab
segmentPolyLine=selectTab.ReturnValue(selectTab.FindField("Shape"),r)
segmentLine=segmentPolyLine.AsLine
segmentStartPoint=segmentLine.ReturnStart
segmentEndPoint=segmentLine.ReturnEnd
Chord_length=segmentStartPoint.Distance(segmentEndPoint)
selectTab.setvalue(chLengthField,r,Chord_length)
end
```

1.14 Calculate Radius and Degree of Curvature of Roadware Curves

1.14.1 <u>Objective</u>
To calculate the radius and degree of curvature of each roadware curve.

1.14.2 <u>Process</u>
- Export the dbf tables of "Manual_dissolve.shp", "Rdware00_dissolve.shp", and "Rdware99_dissolve.shp" into MS-Excel. Name them "Manual_dissolve.xls", "Rdware00_dissolve.xls", and "Rdware99_dissolve.xls" respectively.
- Using the formulas in "degree.xls" or "radius.xls" calculate the radius and degree of curvature for all the roadware curves.

- For curves with radius and/or degree value less than or equal to zero, replace the radius and degree values with 99999.
- Convert "Manual_dissolve.xls" to "Manual_degree.dbf". Similarly, convert "Rdware00_dissolve.xls" to "Rdware00_degree.dbf", and "Rdware99_dissolve.xls" to "Rdware99_degree.dbf".

1.15 Generate Statewide Roadware Curve Database

1.15.1 Objective

To generate the statewide roadware curve database by merging the three different roadware curve databases.

1.15.2 Process

- Add "Manual_degree.dbf", "Rdware00_degree.dbf", and "Rdware99_degree.dbf" tables to the Arc View Project "latest_curves.apr".
- Join "Manual_degree.dbf" to the attribute table of "Manual_dissolve.shp" based on polygon id. Similarly, join "Rdware00_degree.dbf" to the attribute table of "Rdware00_dissolve.shp", and "Rdware99_degree.dbf" to the attribute table of "Rdware99_dissolve.shp".
- Add a source field to the attribute tables of "Manual_dissolve.shp", "Rdware00_dissolve.shp", and "Rdware99_dissolve.shp". Name the source for "Manual_dissolve.shp" as 'Manual', for "Rdware00_dissolve.shp" as 'Rd00', and for "Rdware99_dissolve.shp" as 'Rd99'.
- Convert "Manual_dissolve.shp" to "Manual_curves.shp", "Rdware00_dissolve.shp" to "Rdware00_curves.shp", and "Rdware99_dissolve.shp" to "Rdware99_curves.shp"
- Using the merge themes option in Geo processing wizard, merge "Manual_curves.shp", "Rdware00_curves.shp", and "Rdware99_curves.shp". Name the merge as "Statewide_pri_curves.shp"

1.16 Assign Polygon Ids to Primary Crashes

1.16.1 Objective

To assign unique polygon id to all the crashes which occurred on primary curves.

1.16.2 Why

All the crashes occurring on primary curves would be associated with a polygon id corresponding to the polygon they belong to. This would help in counting the number of crashes on each primary curve.

Process

- Using the assign data by location option in Geo processing wizard, assign polygon ids to crashes occurring on primary curves. Assign data to "Pri_nonint_89-98.shp" from "Rdware_polygon.shp" and then assign data to "Pri_nonint_89-98.shp" from "Digicurve_polygon.shp". Name the polygon ids from "Rdware_polygon.shp" as 'Polygon_id_rd' and the polygon ids from "Digicurve_polygon.shp" as 'Polygon_id_man'
- In order to identify the crashes which occurred on the curves on the primary road network, query the attribute table of "Pri_nonint_89-98.shp" as follows: Polygon_id_rd>0 or Polygon_id_man>0. Save the selected set of crashes as "Pri_curve_crashes.shp".

- To merge the two different polygon id fields (Polygon_id_rd and Polygon_id_man) into one, query the attribute table of "Pri_curve_crashes.shp" as follows: Polygon_id>0. For the selected set of crashes, calculate ' Polygon_id_rd' = 'Polygon_id_man'.

2   Statewide Fixed-object Crash Locations

2.1   "All" Fixed-object Struck Crashes

Identify fixed-object crashes
- Join "A" records shape file and "B" records dbf file
- Query the joined "B" table to select statewide fix-object crashes

  [fix_obj_st] > 1 OR [acc_type] = 18

- Link the highlighted records in the "B" table to "A" records file (active "B" file and clicked [crash_key] fields)
- Remove all joins in the "B" table
- Remove all links in the "B" table
- Repeat the procedure for each year (i.e., 1989 through 1998 crash data)
- Merge all new linked "A" files to zc1a89_98.shp file using Geoprocess--only fix-object crashes are contained in the merged file

Merge 1989 through 1998 "B" records
- Export the highlighted records in "B" tables to new tables (e.g., b89.dbf, b90.dbf, ..., b98.dbf)
- Add script append.ave located on g drive
- Compile and run the script
- Save the merged table as b89_98.dbf

Merge 1989 through 1998 "C" records--needed for the [severity] field (e.g., fatal, major, minor, and possible injuries):
- Link the highlighted records in each "B" table to its associated "C" table (active "B" file and clicked [crash_key] fields)
- Export the selected records in "C" tables to new tables (e.g., c89.dbf, c90.dbf, ..., c98.dbf) using the append.ave script after compiling and running the script
- Save the merged table as c89_98.dbf

- Join st_road.shp and zc1a89_98.shp (clicked [shape] fields)

Select assigned crash records within given boundaries (rural areas within 50 meters, non-rural areas within 20 meters) that occurred at non-intersection locations:
- Rename the newly created [distance] field to [distance_j]
- Query the joined zca189_98.shp

  ([city] = 0 AND [distance_j] <= 50) OR ([city] <> 0 AND [distance_j] <= 20) AND ([int_class] = 0)

Calculate dollar loss using the c89_98.dbf table:
- Add a new field: [$value]
- Query for injury severity: [severity] = 1 (fatal)

- Field/Calculate to populate the [$value] field for the highlighted records with 800000
- Repeat the same procedure for [severity] equals to 2 (major), 3 (minor), 4 (possible), and 0 (unknown) using 120000, 8000, 2000, and 0; respectively
- Summarize based on [crash_key] and add sum for [$value]
- Save the summarized table as cost_fo.dbf--this table contains total injury cost for each crash

- Join cost_fo.dbf and zc1a89_98.shp (clicked [crash_key] fields)
- Join table containing [AADT], [IRI], [width], and [year] fields and zc1a89_98.shp (clicked [road_link] fields)
- Convert zc1a89_98.shp to a new shape file: 89_98_fixed.shp--the new shape file contains all the required fields for ranking high fixed-object crash locations

- Open 89_98_fixed.shp file
- Summarize based on [road_link] field
- Add averages for [AADT] and [lane_length], and sums for [prop_dmg], and [$value] fields
- Save the new table as rank_fixed.dbf

Create a table for fixed object struck types
- Hide all fields except [crash_key] and [fix_obj_st] fields in the b89_98.dbf table
- Join b89_98.dbf and 89_98_fixed.shp (clicked [crash_key] fields)
- Hide all fields except [road_link] and [fix_obj_st] fields in the joined 89_98_fixed.shp
- Export the two fields into a new dbf file: fixed_obj_stk.dbf
- Open fixed_obj_stk.dbf in Excel
- Create a pivot table; select Road_link for row, fix_obj_stk for column, and count Road_link for data
- Copy and paste each pivot table into a new Excel file and save it as fixed_obj_stk.dbf

- Open fixed_obj_stk.dbf in Arcview
- Join rank_fixed.dbf and fixed_obj_stk.dbf tables (clicked [road_link] fields)

- Query the joined rank_fixed.dbf to select the links with more than two fixed-object crashes

  [count] > 2

- Disjoin rank_fixed.dbf table
- Export the highlighted records to rank_fixed_gt2.dbf file
- Open rank_fixed_gt2.dbf in Excel
- Conduct a ranking according to the Iowa DOT procedure
- Open the ranked rank_fixed_gt2.dbf in Arcview
- Select the top 30 locations: ([final_rank] < 31)
- Export the highlighted records to 30_fixed_gt2.dbf
- Join 30_fixed_gt2.dbf and st_road.shp (clicked [road_link] fields)

- Select the 30 joined records in the st_road.shp
- Convert to a new shape file: t_30_fixed_gt2.shp to show the top 30 locations on the map
- Link t_30_fixed_gt2.shp and 89_98_fixed.shp files to inspect the identified high crash locations

2.2 Utility Pole Struck Crashes

Identify utility pole struck crashes in "B" records
- Query b89_98.dbf to select statewide utility pole struck crashes

  [fix_obj_st] = 15

- Link the highlighted records in the b89_98.dbf to zc1a89_98.shp (active b89_98.dbf and clicked [crash key] fields)

- Convert zc1a89_98.shp to a new shape file: zc1a89_98_ut.shp
- Join st_road.shp and zc1a89_98_ut.shp (clicked [shape] fields)

- Rename the newly created [distance] field to [distance_j]
- Query the joined zca189_98_ut.shp

  ([city] = 0 AND [distance_j] <= 50) OR ([city] <> 0 AND [distance_j] <= 20) AND ([int_class] = 0)

- Query b89_98.dbf to select statewide utility pole struck crashes

  [fix_obj_st] = 15

- Link the highlighted records in the b89_98.dbf to c89_98.dbf (active b89_98.dbf and clicked [crash key] fields)
- Summarize based on [crash_key] and add sum for [$value]
- Save the summarized table as cost_fo_ut.dbf--this table contains total injury cost for all utility pole crashes

- Join cost_fo_ut.dbf and zc1a89_98_ut.shp (clicked [crash_key] fields)
- Convert zc1a89_98_ut.shp to a new shape file: 89_98_fixed_ut.shp--the new shape file contains all the required fields for ranking high utility pole crash locations
- Add [AADT], [lane_length] fields to zc1a89_98_ut.shp using the 89_98_fixed.shp (clicked [road_link] fields)

- Open 89_98_fixed_ut.shp file
- Summarize based on [road_link] field
- Add averages for [AADT] and [lane_length], and sums for [prop_dmg], and [$value] fields
- Save the new table as rank_fo_ut.dbf

- Query the rank_fo_ut.dbf to select the links with more than two utility pole crashes

  [count] > 2

- Export the highlighted records to rank_fo_ut_gt2.dbf file
- Open rank_fo_ut_gt2.dbf in Excel
- Conduct a ranking according to the Iowa DOT procedure
- Open the ranked rank_fo_ut_gt2.dbf in Arcview
- Select the top 30 locations: ([final_rank] < 31)
- Export the highlighted records to 30_fo_ut_gt2.dbf
- Join 30_fo_ut_gt2.dbf and st_road.shp (clicked [road_link] fields)
- Select the 30 joined records in the st_road.shp
- Convert to a new shape file: t_30_fo_ut_gt2.shp to show the top 30 locations on the map
- Link t_30_fo_ut_gt2.shp and 89_98_fixed_ut.shp files to inspect the identified high crash locations

3 Intersections along Rural Four-Lane Expressways

3.1 *Identify Rural Expressways*

- Query Iowa DOT roadway centerline theme to select rural expressways. For this study, rural expressways were defined as non-Interstate roadways with four (or more) lanes located outside of corporate limits.

  ([Sys]<>1) and ([City]=0) and ([Numlanes]>=4)

3.2 *Identify Intersecting (Proximate) Roadways*

- Select (by Theme) all roadway segments from the centerline theme that are within 16 meters of the rural expressways (previous selection set). This value may be adjusted, but, if too large, too many roadways will be selected.
- Add these records to the existing selection set.
- Save all records (rural four-lane expressways and intersecting roadways) as new theme, "rural_express.shp", and add to view.

3.3 *Identify Rural, Intersection Crashes*

- Query the GIS-ALAS "A" records theme(s) to select rural, intersection crashes. For this study, rural, intersection crashes were defined as those indicated as rural, non-interchange crashes possessing a valid intersection node id and intersection class code. These selection criteria yield all rural, intersection crashes and are not limited to expressways.

  ([Rur_urb]="R") and ([Int_id]<>999999) and ([Int_class]>0) and
  (([Road_char]>=11) and ([Road_char]<=14))

- Repeat this query for all "A" record themes containing data from years of interest.

3.4 *Identify Rural, Expressway Intersection Crashes*

- Select (by Theme) all rural, intersection crashes, from the "A" records theme(s), previous selection set, that are within 50 meters of the rural expressways (selection set from "Identify Intersecting Roadways"). This selection may yield non-expressway crashes as well, specifically intersection crashes occurring along the intersecting roadways.
- Merge selected features from all "A" record themes and save as "int94_98.shp". (This represents a five-year analysis period.)

- Notes:
- A value of 50 meters was utilized because it is approximately equal to the accuracy of the cartographic data.

3.5 *Determine Daily Entering Vehicles (DEV) at Intersections*

(Note: If DEV is known for all [Int_id], the following procedure is not required.)

3.5.1 Create Single Point Feature at Intersection Sites

- Edit "int94_98.shp" and add a new field: [Coint_id], string(8) or decimal(8).
- Update [Coint_id] with the concatenation of [Co] and [Int_id].

- [Co] + [Int_id]

- Using the Geoprocessing Wizard, dissolve rural, expressway intersection crashes by [Coint_id]. Create output file "int94_98x.shp". Summarize [Prop_dmg] by sum for use in crash ranking. Crash frequency [Count] is calculated automatically and will also be used in crash ranking.
  - Other fields may also be summarized to yield the general intersection physical characteristics and crash history. In addition, discrepancies among recording officers may become apparent through the summary data.
  - Potential fields on interest include: [Vehicles] by sum, [Killed] by sum, [Injured] by sum, [Prop_dmg] by sum, [Severity] by minimum, [County] by minimum, [City] by minimum, [Rur_urb] by first, [Route] by first, [Int_class] by average, [Road_class] by average, [Road_char] by average, [Road_geo] by average, and [Locality] by average.

  Notes:
  - This step not only yields a single point feature at each crash site with the selected, summarized "A" record attributes, but the total number (count) of crashes at the site as well.
  - This step is necessary because the primary emphasis of analysis is location-based, not incident-based. However, for incident-based analysis, all crashes may be tied back to a specific site using the unique [Coint_id].
  - [Int_id] is only unique if proceeded by county number, [Co].
  - Although infrequent, crashes at a single site may incorrectly posses different [Coint_id] values, resulting in several disparate locations with the same [Coint_id]. These locations must be assessed independently.

3.5.2 Buffer Intersection Sites

- With the "int94_98x.shp" theme active, load, compile, and run "bufferid.ave" script.
  - Use the [Cont_id] field to identify output buffers and set buffer radius approximately equal to 50 meters (the cartographic accuracy).
  - Save buffers as "int94_98buf.shp".

Notes:
  - This script creates a buffer around each intersection and assigns [Coint_id] to the buffer.
  - The newly created buffers will be used to assign intersection approaches to each intersection.

3.5.3   Identify Roadway Segments Intersecting Intersection Buffers

- Using the Geoprocessing Wizard, clip the "rural_express.shp" theme with the "int94_98buf.shp" theme. Save the resulting, partial roadway centerline theme as "re_int.shp".

3.5.4   Assign Intersection Identifier to Intersection Approaches

- Using the Geoprocessing Wizard, assign data by location from the "int94_98buf.shp" theme to the "re_int.shp" theme.

3.5.5   Calculate Number of Unique Centerline Segments per Intersection

- Summarize [Input Shape ID] ([Coint_id]) field of "re_int.shp" theme. Save resulting dbf file as "re_int_sum.dbf".

3.5.6   Modify Table Definitions for Approach Assignment

- Assign the number of centerline segments to each intersection point feature. This is accomplished by joining "re_int_sum.dbf" to "re_int" theme, using [Coint_id] and saving the new theme as "re_int2.shp".   A [Count] field is now present in "re_int2.shp". This represents the number of unique centerline segments located within the intersection buffer.

  Note:
  - Centerline segments may not terminate at intersections.

- Edit "re_int2.shp" and add field: [Seg_type], string(1). This field will be populated with one of the following: "E" = centerline segment ends/terminates at intersection, "T" = centerline segment continues through intersection, "D" = centerline segment should not be associated with intersection.

- Edit "rural_express.shp" and add fields: [Coint_id], string(8) or decimal(8), [Count], decimal(1), and [Seg_type], string(1).

- Create new table, "re_int2_append.dbf". Add fields: [Road_link], [Coint_id], string(8) or decimal(8), [Count], decimal(1), and [Seg_type], string(1). As necessary, records will be added this table to accurately and completely reflect intersection approaches.

3.5.7   Visually Inspect Intersection Sites

- Sort "re_int2.dbf" by [Input Shape Id] ([Coint_id]).
- Select records (centerlines) possessing the same [Input Shape Id] and fit these records in the active view. Assess whether the selected records are correctly attributed to the active intersection.
  - If a segment is correctly attributed to an intersection, update the [Count] and [Seg_type] fields accordingly.
  - If a segment appears to be incorrectly attributed to an intersection, update the [Coint_id] field with null. This may occur if concurrent segments of roadway (along a common intersection approach) fall within the intersection buffer.

- If an approach segment appears to be missing, identify the appropriate segment in "rural_express.shp" and update the [Coint_id], [Count], and [Seg_type] fields. If this record has already been assigned to another intersection, update [Road_link], [Coint_id], [Count], and [Seg_type] in the "re_int2_append.dbf" file. This may occur if a segment lies within multiple intersection buffers.
- Repeat for all intersections.

3.5.8   Aggregate Intersection Approach Records
- Select all records from "re_int2.dbf", "rural_express.shp", and "re_int2_append.dbf" where [Coint_id], or [Input Shape ID], is greater than zero or not null.
- Export the selected records from the aforementioned tables to individual dbf files.
- Using Microsoft Excel, format and append the exported tables. The final table should contain the following fields, [Road_link], [Coint_id] ([Input Shape Id]), [Count], [Seg_type], as well as new, blank fields of [Aadt], decimal(8), [Adj_aadt], decimal(8), and [Yr_cnt], decimal(4). Save this table as "int1.dbf".

3.5.9   Calculate DEV
- Within ArcView, join "int1.dbf" with a dbf file containing roadway centerline data, specifically [Road_link], [Aadt], and [Yr_cnt] fields, using [Road_link]. The [Road_link] field represents the unique, Base Record segment identifier.
- Update the [Aadt] and [Yr_cnt] fields in "int1.dbf" with the values contained in the corresponding fields from the joined table. If the field names are the same, aliases must be assigned to the common fields in one of the tables.
- Select from "int1.dbf" where [Seg_type]="E". Calculate [Adj_aadt]=[Aadt]/2.
- Switch selection and calculate [Adj_aadt]=[Aadt].
- Select none and save table "int1.dbf".
- Summarize "int1.dbf" on [Input Shape Id] ([Coint_id]), calculating [Adj_aadt] by sum. The resulting [Adj_aadt_sum] field represents intersection daily entering vehicles (DEV). Save the summary table as "Dev.dbf".

3.6   Determine Total Injury-related Loss at Intersections
- Link GIS-ALAS "C" record table to "int94_98" on [Crash_key]. Only display [Crash_key] and [Severity] fields from "C" records table.
- Select crashes from the merged "A" records which occur in the same year as the crashes represented in the "C" records table. This query will select both the "A" records of interest as well as the corresponding "C" records.
  - For example, if the "C" records table is "zc1c1998.dbf", representing 1998 crashes, perform the following query on the merged "A" records:

    ((([Crash_key]>=1998000000) and ([Crash_key]<1999000000))

    where [Crash_key] is a numeric field.

- Remove all links from the "C" and merged "A" records tables. Clear all selected records (select none) and link a different "C" records table, representing a different year, to the merged "A" records.

- Repeat until the appropriate "C" records for all analysis years have been selected.
- Export, from all "C" records tables, all selected records.
- Append all newly exported "C" records tables by loading, compiling, and running "table_append.ave" script. Save appended tables as "sev94_98.dbf".
- Edit "sev94_98.dbf" and add fields: [Coint_id], string(8) or decimal(8), and [Sev_loss], decimal(8).
- Join "int94_98x" to "sev94_98" using [Crash_key] and update [Coint_id] with [Coint_id] from "int94_98x".
- Open "sev94_98.dbf" in Microsoft Excel. Use an "IF" statement to update [Sev_loss] based on the value of [Severity], e.g.

  [Sev_loss]=IF([Severity]=1,800000,IF([Severity]=2,120000,IF([Severity]=3,8000,2000)))

- Within Excel, create a pivot table report using [Coint_id] as the rows of the table and the sum of [Sev_loss] as the data. This yields the total Export the pivot table as "sev_loss.dbf".

3.7 *Rank Intersections*
- Within ArcView, join "sev_loss" and "Dev" to "int94_98x" using [Coint_id].

  Note:
  - Not all records will possess [Adj_aadt_sum] (DEV) or [Sev_loss] values. This occurs when the location is no longer considered in analysis, or when no injuries resulted, or were reported, at an intersection.

- Select all records where [Adj_aadt_sum] (DEV) is greater than zero and convert to a new shape file, "int94_98x_sum.shp"
- Open "int94_98x_sum.dbf" in Excel and calculate crash rates and ranks.
  - For each row:
    - Sum the [Sev_loss] and [Sum_prop_dmg] columns. This provides a value for total loss [Tot_loss] at the intersection.
    - Calculate [Crash_rate] = ([Freq]*[1,000,000])/(365*DEV*5), where the number of analysis years equals five.
    - Use Excel's "Rank" function to independently rank intersections by crash rate, crash frequency, and total loss. For example, if [Tot_loss] is located in column "B", and the database contains 353 records, the rank for record one is calculated using the following expression,

      =RANK(B2,$B$2:$B$354).

      The expression in this form assigns ranks (sorts) in descending order.

    - Calculate the sum the loss, crash rate, and crash frequency ranks.
    - Rank the sum of all ranks in ascending order. For example, if the sum of ranks is located in column "O", the following expression applies,

=RANK(O2,$O$2:$O$354,1)

This yields the overall ranking of the intersection with respect to all other intersections.

4   Centerline Crossing Head-on Crash Locations on Rural Two-Lane Paved Road

Identify centerline crossing head-on crashes:
- Join "A" records shape file and "B" records dbf file
- Query the joined "B" table to select statewide fix-object crashes

  [driv_veh1] = 7 OR [driv_veh2] = 7 OR [coll_type] = 1

- Link the highlighted records in the "B" table to "A" records file (active "B" file and clicked [crash_key] fields)
- Remove all joins in the "B" table
- Remove all links in the "B" table
- Repeat the procedure for each year (i.e., 1989 through 1998 crash data)
- Merge all new linked "A" files to ho_a89_98.shp file using Geoprocess--only fix-object crashes are contained in the merged file

Merge 1989 through 1998 "B" records:
- Export the highlighted records in "B" tables to new tables (e.g., ho_b89.dbf, ho_b90.dbf, …., ho_b98.dbf)
- Add script append.ave located on g drive
- Compile and run the script
- Save the merged table as ho_b89_98.dbf

Merge 1989 through 1998 "C" records--needed for the [severity] field (e.g., fatal, major, minor, and possible injuries):
- Link the highlighted records in each "B" table to its associated "C" table (active "B" file and clicked [crash_key] fields)
- Export the selected records in "C" tables to new tables (e.g., ho_c89.dbf, ho_c90.dbf, …., ho_c98.dbf) using the append.ave script after compiling and running the script
- Save the merged table as ho_c89_98.dbf

Create a shape file for the identified rural 2-lane paved links
- Dissolve st_road.shp based on [mslink] field attribute and save the new file as st_road_mslink_dissolved.shp
- Join rural_2lane_paved.dbf (this is a dbf file that contains all rural 2lane paved links) and st_road_mslink_dissolved.shp (clicked [mslink] fields)
- Query the joined st_road_mslink_dissolved.shp to select the rural 2lane paved links

  [surf_type] > 0

- Convert st_road_mslink_dissolved.shp to a new shape file: st_rural_2lane_paved.shp
- Disjoin st_road_mslink_dissolved.shp
- Delete st_road_mslink_dissolved.shp theme

- Join st_rural_2lane_paved.shp and ho_a89_98.shp (clicked [shape] fields)

Select assigned crash records within given boundaries (rural areas within 50 meters) that occurred at non-intersection locations:
- Rename the newly created [distance] field to [distance_j]
- Query the joined ho_a89_98.shp

  [distance_j] <= 50 AND ([int_class] = 0)

Calculate dollar loss using the c89_98.dbf table:
- Add a new field: [$value]
- Query for injury severity: [severity] = 1 (fatal)
- Field/Calculate to populate the [$value] field for the highlighted records with 800000
- Repeat the same procedure for [severity] equals to 2 (major), 3 (minor), 4 (possible), and 0 (unknown) using 120000, 8000, 2000, and 0; respectively
- Summarize based on [crash_key] and add sum for [$value]
- Save the summarized table as cost_ho.dbf--this table contains total injury cost for each crash

- Join cost_ho.dbf and ho_a89_98.shp (clicked [crash_key] fields)
- Join table containing [AADT], [IRI], [width], and [year] fields and ho_a89_98.shp (clicked [road_link] fields)
- Convert ho_a89_98.shp to a new shape file: 89_98_ho.shp--the new shape file contains all the required fields for ranking high head-on crash locations

- Open 89_98_ho.shp file
- Summarize based on [road_link] field
- Add averages for [AADT] and [lane_length], and sums for [prop_dmg], and [$value] fields
- Save the new table as rank_ho.dbf

- Query rank_ho.dbf to select the links with more than two head-on crashes

  [count] > 2

- Export the highlighted records to rank_ho_gt2.dbf file
- Open rank_ ho_gt2.dbf in Excel
- Conduct a ranking according to the Iowa DOT procedure
- Open the ranked rank_ ho_gt2.dbf in Arcview
- Select the top 30 locations: ([final_rank] < 31)
- Export the highlighted records to 30_ho_gt2.dbf
- Join 30_ ho_gt2.dbf and st_rural_2lane_paved.shp (clicked [road_link] fields)
- Select the 30 joined records in the st_rural_2lane_paved.shp
- Convert to a new shape file: t_30_ho_gt2.shp to show the top 10 locations on the map
- Link t_30_ ho_gt2.shp and 89_98_ho.shp files to inspect the identified high crash locations

5 Four-Lane Undivided Corridors with High Crash Occurrences

Analysis, entails: 1) defining four-lane, undivided corridors, 2) calculating corridor length and a weighted AADT for the corridor, and 3) considering all crashes (intersection and non-intersection) along the corridor in rate determination and ranking.

5.1 Identify Four-lane, Undivided Roadways

- Query Iowa DOT roadway centerline theme to select four-lane, undivided roadways. For this study, four-lane undivided roadways were defined as urban, primary roadways with four (or more) lanes and no median and annual traffic less than 14,000.

  ([Sys]<=3) and ([Numlanes]>=4) and ([Med_type]=0) and ([City]>0) and ([Aadt]<=14000) and ([Func]<50)

- The aforementioned selection should then be further limited by lane type. Specifically, the selection set should only include facilities with four through lanes and no center, bi-direction left turn lane. Given the potential complexity of the query, five lane facilities may require visual inspection of the lane types. In addition, lane types may be presented in multiple fields for each lane or a single, combined field representing all lanes. For example, to identify all four lane facilities consisting solely of four through lanes, the following query may be used.

  ([Lane_type]="111100000")

  Once again, all five lane facilities should be visually inspected and added to the current selection set as deemed appropriate. (See the *Base Record Road and Structure Data Manual* for lane type definitions.)

  Save results as "undiv4.shp".

5.2 Define Urban, Four-lane Corridors

- Edit "undiv4". Add "corridor_id" field (number, 4) and "corridor_loc" (string, 10) field. "Corridor_loc" will serve as a single field indicating the general location of a roadway segment.
- Update "corridor_loc" field with the following:

  [Co]+[City]+[St_rte]

- Sort "undiv4" by "corridor_loc". Select common "corridor_loc" values and view the selection set graphically. Corridors may include adjacent roadway segments possessing a different "corridor_id" value. For example, adjacent segments outside of the corporate limit. Update the "corrider_id" field of these records with a unique, integer value.

Add "alt_corrid" field (number 4). This field will be used to represent partial corridors (corridor segments). Define these corridor segments based primarily on location, continuity, and homogeneity in traffic and lane type.

5.3   Create Corridor Coverage

- Edit "undiv4". Add field "wt_aadt" (number 5) and "Leng_mi" (number 6,3).
- If "Lane_leng" is in meters, update "Leng_mi" with segment length in miles:

[Lane_leng]*.0006214

- Summarize "undiv4" on "Corridor_id" (lane_mi.dbf):

Lane_mi: sum

Change field name to "Sum_leng_mi".

- Join "lane_mi.dbf" to "undiv4" on "Corridor_id". Set "Wt_aadt" equal to the following:

([Leng_mi]/[Sum_leng_mi])*[Aadt]

- Using the Geoprocessing Wizard, dissolve "undiv4" on "corridor_id".

Road_link: first
Lane_leng: sum
Wt_aadt: sum

Save as: "undiv4_ag.shp"

[Repeat this for the partial corridors (corridor segments), based on "alt_corrid".]

5.4   Identify Urban, Primary Crashes

- Query the GIS-ALAS "A" records theme(s) to select urban, primary road crashes. For this study, urban, primary road crashes were defined as those indicated as occurring in a city on an Iowa or US route. This selection criteria yield all urban, primary road crashes and are not limited to four lane, undivided roadways.

((([Rur_urb]="U") or ([City]>0)) and ([Road_class]=2)

- Repeat this query for all "A" record themes containing data from years of interest.

5.5   Identify Urban, Primary Crashes on Corridors of Interest

- Select (by Theme) all urban, primary crashes, from the "A" records theme(s), previous selection set, that are within 16 meters of the four lane undivided roadways.

This selection may yield crashes on adjacent, primary roadways occurring within 16 meters of the roadways of interest.
- Merge selected features from all "A" record themes and save as "crashmerge.shp". (This represents a five-year analysis period.)

Notes:
- A value of 16 meters was utilized because it is approximately equal to the accuracy of the cartographic data.

5.6   Assign Corridor Attributes to Crashes
- Using the Geoprocessing Wizard, assign data by location from the "undiv4_ag.shp" theme to the "crashmerge.shp" theme. The attributes of interest are "wt_aadt", "lane_leng", and "corridor_id" (unique segment identifier).

[Repeat this for the partial corridors (corridor segments), based on "alt_corrid".]

5.7   Determine Total Injury-related Loss along Corridors
- Link GIS-ALAS "C" record table to "crashmerge" on [Crash_key]. Only display [Crash_key] and [Severity] fields from "C" records table.
- Select crashes from the merged "A" records which occur in the same year as the crashes represented in the "C" records table. This query will select both the "A" records of interest as well as the corresponding "C" records.
    - For example, if the "C" records table is "zc1c1998.dbf", representing 1998 crashes, perform the following query on the merged "A" records:

    ((([Crash_key]>=1998000000) and ([Crash_key]<=1999000000))

    where [Crash_key] is a numeric field.

- Remove all links from the "C" and merged "A" records tables. Clear all selected records (select none) and link a different "C" records table, representing a different year, to the merged "A" records.
- Repeat until the appropriate "C" records for all analysis years have been selected.
- Export, from all "C" records tables, all selected records.
- Append all newly exported "C" records tables by loading, compiling, and running "table_append.ave" script. Save appended tables as "inj_sev.dbf".
- Edit "inj_sev" and add fields: [Corridor_id], string(8) or decimal(8), and [Sev_loss], decimal(8).
- Join "crashmerge" to "inj_sev" using [Crash_key] and update [Corridor_id] with [Coint_id] from "crashmerge".
- Open "inj_sev.dbf" in Microsoft Excel. Use an "IF" statement to update [Sev_loss] based on the value of [Severity], e.g.

    [Sev_loss]=IF([Severity]=1,800000,IF([Severity]=2,120000,IF([Severity]=3,8000,2000)))

- Within Excel, create a pivot table report using [Corridor_id] as the rows of the table and the sum of [Sev_loss] as the data. This yields the total Export the pivot table as "sev_loss.dbf".

[Repeat this for the partial corridors (corridor segments), based on "alt_corrid".]

5.8   Rank Corridors

- Within ArcView, summarize "crashmerge" on "Corridor_id":

Prop_dmg: sum
Leng_mi: first
Wt_aadt: first

Save as "crashmerge_sum.dbf".

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- Within ArcView, join "sev_loss" to "crashmerge_sum" using [Corridor_id]. Export as "crashmerge_final.dbf".
- Open "crashmerge_final.dbf" in Excel and calculate crash rates and ranks.
  - For each row:
    - Sum the [Sev_loss] and [Sum_prop_dmg] columns. This provides a value for total loss [Tot_loss] at the intersection.
    - If Sum_leng_miles is less than 0.6 miles,
    - [Crash_rate] = ([Freq]*[1,000,000])/(365*Sum_leng_mi*Wt_aadt*5), where the number of analysis years equals five.
    - If Sum_leng_miles is greater than or equal to 0.6 miles,
    - [Crash_rate] = ([Freq]*[1,000,000])/(365*(Sum_leng_mi/0.3)*Wt_aadt*5), where the number of analysis years equals five.
    - Use Excel's "Rank" function to independently rank intersections by crash rate, crash frequency, and total loss. For example, if [Tot_loss] is located in column "B", and the database contains 353 records, the rank for record one is calculated using the following expression,

      =RANK(B2,$B$2:$B$354).

      The expression in this form assigns ranks (sorts) in descending order.

    - Calculate the sum the loss, crash rate, and crash frequency ranks.
    - Rank the sum of all ranks in ascending order. For example, if the sum of ranks is located in column "O", the following expression applies,

      =RANK(O2,$O$2:$O$354,1)

      This yields the overall ranking of the corridors with respect to all other corridors.

- Update the named range of the dbf file and save. Join these results to "undiv4_ag" to view the locations spatially.

[Repeat this for the partial corridors (corridor segments), based on "alt_corrid".]