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Evaluating traffic safety network screening: an initial framework utilizing the hierarchical Bayesian philosophy

Michael David Pawlovich
Iowa State University

Evaluating traffic safety network screening:

An initial framework utilizing the hierarchical Bayesian philosophy

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Michael David Pawlovich

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Program of Study Committee:
Reginald R. Souleyrette, Major Professor
Alicia Carriquiry
Shauna Hallmark
Edward Kannel
David Plazak

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Graduate College
Iowa State University

This is to certify that the master's thesis of

Michael David Pawlovich

has met the requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For the Major Program

I dedicate this effort
to those I have been blessed
to share my life with:
my family, friends, and colleagues.

May this research lead to
increased safety and enjoyment
for all motorists.

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ABSTRACT

Highway crashes are the leading cause of death for those under age 34 in the United States. These crashes result in over 40,000 deaths per year (500,000 worldwide), and their impact on the national economy is estimated to be more than 230 billion dollars. Highway safety is identified as the top priority of the United States Department of Transportation (US DOT), and funds dedicated to addressing the problem are expected to increase substantially with the reauthorization of the federal transportation act.

Highway safety is a multidisciplinary issue, addressed chiefly by engineering, enforcement, education, and emergency response. An important tool for these disciplines is the safety improvement candidate location (SICL) list. SICL lists provide a method of identifying high crash locations for potential mitigation.

Highway agencies develop SICL lists using crash data. Typically, crash frequency, crash rate, loss, or some combination is used to rank all (or the worst) locations in a particular jurisdiction. Classical statistical techniques are applied. In some cases, simple analyses based on crash or fatal crash frequency are used to draw attention to "problem" locations.

Simple ranked lists suffer from methodological and practical limitations. Chief among these is the inability of such simple lists to identify "sites with promise", sites where mitigation has the best chance of reducing future injury, death, and loss. To address this, agencies representing each discipline generally examine top sites prior to resource dedication. Engineering and enforcement applications are more prevalent. This process is resource intensive. In addition, the efforts of different safety interests in an area are often not well coordinated.

For over 20 years, a technique known as empirical Bayesian (EB) has been proposed to address limitations of conventional SICL methods. EB helps identify sites where mitigation might be most effective, increases confidence in estimates, and provides information on the relative safety of ranked sites. Recently, EB has risen to the forefront of highway safety systems development and is being widely implemented at the national level. State and local agencies primarily continue to develop SICL lists based on long-standing assessment or statistical procedures.

EB is attractive because it allows decision makers to more reliably estimate the potential for reduction in crashes at specific sites. However, EB requires development of functions to compute expected safety performance for classes of road types. To be most effective, the technique also requires a priori development of accident modification factors. To determine functional form, EB requires significant database development. These requirements add significant expense.

Inexpensive access to powerful computers and development of advanced statistical sampling techniques allow a general form of Bayesian statistics, called hierarchical Bayesian, to be applied to highway safety. Hierarchical Bayesian eliminates the need for a priori functions and factors. Unlike EB, a hierarchical Bayesian approach can readily (i.e., without development of functions and factors) incorporate additional information. It can also be used to explicitly identify important relationships between causal factors and safety performance. The hierarchical Bayesian approach uses data to define the results, based on a level of uncertainty as indicated by the analyst. This dissertation discusses development of SICL lists and evaluates the potential of Bayesian statistics to greatly improve their utility.

CHAPTER 1. INTRODUCTION

Highway crashes are the leading cause of death for those under age 34 in the United States (CDC 2002). These crashes result in over 40,000 deaths per year (500,000 worldwide), and their impact on the national economy is estimated to be more than 230 billion dollars (NHTSA 1994, 1995,1996,1997,1998,1999,2000,2002a,b; Runge 2002; Schluter et al. 1997). Highway safety is identified as the top priority of the United States Department of Transportation (US DOT) (Runge 2002), and funds dedicated to addressing the problem are expected to increase substantially with the reauthorization of the federal transportation act.

Highway safety is a multidisciplinary issue, addressed chiefly by engineering, enforcement, education, and emergency response (SMS 2002a,b). An important tool for these disciplines is the safety improvement candidate location (SICL) list. SICL lists provide a method of identifying high crash locations for potential mitigation (Estochen 1999; FHWA 1979; HRGreen 2001; Iowa DOT 2002; Ogden 1996; SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000).

Highway agencies develop SICL lists using crash data. Typically, crash frequency, crash rate, loss, or some combination is used to rank all (or the worst) locations in a particular jurisdiction (Estochen 1999; FHWA 1979; HRGreen 2001; Iowa DOT 2002; Ogden 1996; SEMCOG 1997; SMS 2002a,b; Traffic Institute 1999; TRB 1975,1986,2000). Classical statistical techniques are applied. In some cases, simple analyses based on crash or fatal crash frequency are used to draw attention to "problem" locations (State Farm 2001).

Simple ranked lists suffer from methodological and practical limitations. Chief among these is the inability of such simple lists to identify "sites with promise" (Hauer 1996; Hauer et al. 2002b; ITE 1999; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e), sites where mitigation has the best chance of reducing future injury, death, and loss. To address this, agencies representing each discipline generally examine top sites prior to resource dedication. Engineering and enforcement applications are more prevalent. This process is resource intensive. In addition, the efforts of different safety interests in an area are often not well coordinated.

For over 20 years, a technique known as empirical Bayesian (EB) has been proposed to address limitations of conventional SICL methods (Davis and Yang 2001; Hauer 1986,1996; Hauer et al. 1986,1988,2002b; Higle and Hecht 1989; Higle and Witkowski 1988; ITE 1999; Melcher et al. 2001; Morris 1988; Pendleton 1988; Persaud 1988; Persaud and Hauer 1984; Saccomanno et al. 2001; Schluter et al. 1997). EB helps identify sites where mitigation might be most effective, increases confidence in estimates, and provides information on the relative safety of ranked sites. Recently, EB has risen to the forefront of highway safety systems development (Harwood 1995; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e; Paniati and True 1997; Reagan 1994; US DOT 2000) and is being widely implemented at the national level. State and local agencies primarily continue to develop SICL lists based on long-standing assessment or statistical procedures.

EB is attractive because it allows decision makers to more reliably estimate the potential for reduction in crashes at specific sites. However, EB requires development of functions to compute expected safety performance for classes of road types (Hauer et al. 2002a; Kononov and Janson 2002; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e; Persaud et al. 2002). To be most effective, the technique also requires a priori development of accident modification factors (MRI 2002e,2003d; Ogden 1996; Tarko et al. 1998,1999). To determine functional form, EB requires significant database development. These requirements add significant expense.

Inexpensive access to powerful computers and development of advanced statistical sampling techniques allow a general form of Bayesian statistics, called hierarchical Bayesian, to be applied to highway safety (Carlin and Louis 2000; Congdon 2001; Gelman et al. 1998; Gilks et al. 1998). Hierarchical Bayesian eliminates the need for a priori functions and factors. Unlike EB, a hierarchical Bayesian approach can readily (i.e., without development of functions and factors) incorporate additional information. It can also be used to explicitly identify important relationships between causal factors and safety performance. The hierarchical Bayesian approach uses data to define the results, based on a level of uncertainty as indicated by the analyst. This dissertation discusses development of SICL lists and evaluates the potential of Bayesian statistics to greatly improve their utility.

The Safety Problem

The safety problem can be characterized by interest and impact. Highway safety has a long history of significant local, state, and national attention. Recently, federal funding has increased and draft legislation of the next federal transportation act promises a stronger focus on safety..

Interest

Numerous groups advocate a strong response to the highway safety problem. These groups vary considerably and include federal, state, and local governments, professional associations, and advocacy groups. Each has similar interests but different, often competing, goals.

Traffic safety is a multidisciplinary issue. Professionals in engineering, enforcement, education, and emergency response are engaged in safety planning, design, and operations. Each discipline has its own focus and groups may compete for funding. In addition, public and political agendas sometimes influence funding and responses to specific problems (e.g., installation of a traffic signal at an intersection that is considered unsafe by citizens even though warrants for installation are not met).

Professional associations in each discipline monitor and promote safety initiatives, recommend and evaluate practices, and admonish unsafe practices. While some associations are primarily traffic safety oriented, most have broader goals. Some associations, such as those in the transit, trucking, and loss recovery (e.g., insurance) professions, have alternative primary goals.

Numerous advocacy groups exist, most with extremely focused agendas. Several prominent advocacy groups are primarily concerned with alcohol-related crash reduction (i.e., Mothers Against Drunk Driving [MADD], Record Artists, Actors, and Athletes Against Drunk Driving [RADD], and Students Against Destructive Decisions [SADD]). Others seek decreases in unsafe driving practices (e.g., speeding, red-light-running, drowsy driving). These groups lobby for funds, sponsor public service announcements (PSA), and perform other types of outreach.

The various groups share the goal of improving traffic safety, and over the past few decades significant gains have been made (NHTSA 1994,1995,1996,1997,1998,1999,2000,2002a,b; SMS 1996,1997,1998,1999,2000,2001,2002c). These gains were made through a combination of improved vehicles, highways, education, emergency response, and education. However, the downward trends in fatalities and injuries have been reversing recently. Numerous potential causes have been suggested, including the continued increase in travel, legislative changes (e.g., higher speed limits), and driver behavior (e.g., red-light running, road rage). Whatever the cause, fatalities and injuries are increasing and more attention is being directed toward this problem.

Each group has a method of prioritizing its efforts. Historically safety engineers have used ranking lists to prioritize analysis of problem sites. Enforcement has often used simple geographic representations (e.g., pin maps) to indicate problem areas. Other groups have used annual crash or injury totals within regions (e.g., city, county) for comparison purposes. Many times these regional totals are developed for specific concerns (e.g., alcohol-related crashes, unbelted fatalities). However, the various schemes for directing resources are often disjointed and disputable and may even result in less efficient resource allocation.

Impact

In 2001, 42,000 people died and 3 million more were injured in crashes nationwide (NHTSA 2002a). Crash fatalities and injuries have been steadily increasing (NHTSA 1994, 1995,1996,1997, 1998,1999,2000,2002a,b). Motor vehicle crashes rank above homicide and suicide as the leading cause of death for Americans under age 34 (CDC 2002).

The current American Association of State Highway and Transportation Officials (AASHTO) national goal is to achieve a fatality rate of 1.0 fatality per 100 million vehicle-miles traveled (HMVMT) (AASHTO 2003; Runge 2002). Despite an increase in crashes, the national rates (measured against per-mile vehicular travel) have declined over the past 10 years, as shown in Figure 1.1 (NHTSA 1994, 1995,1996,1997,1998,1999,2000,2002a,b). However, this trend of reduced rates has leveled off in recent years.

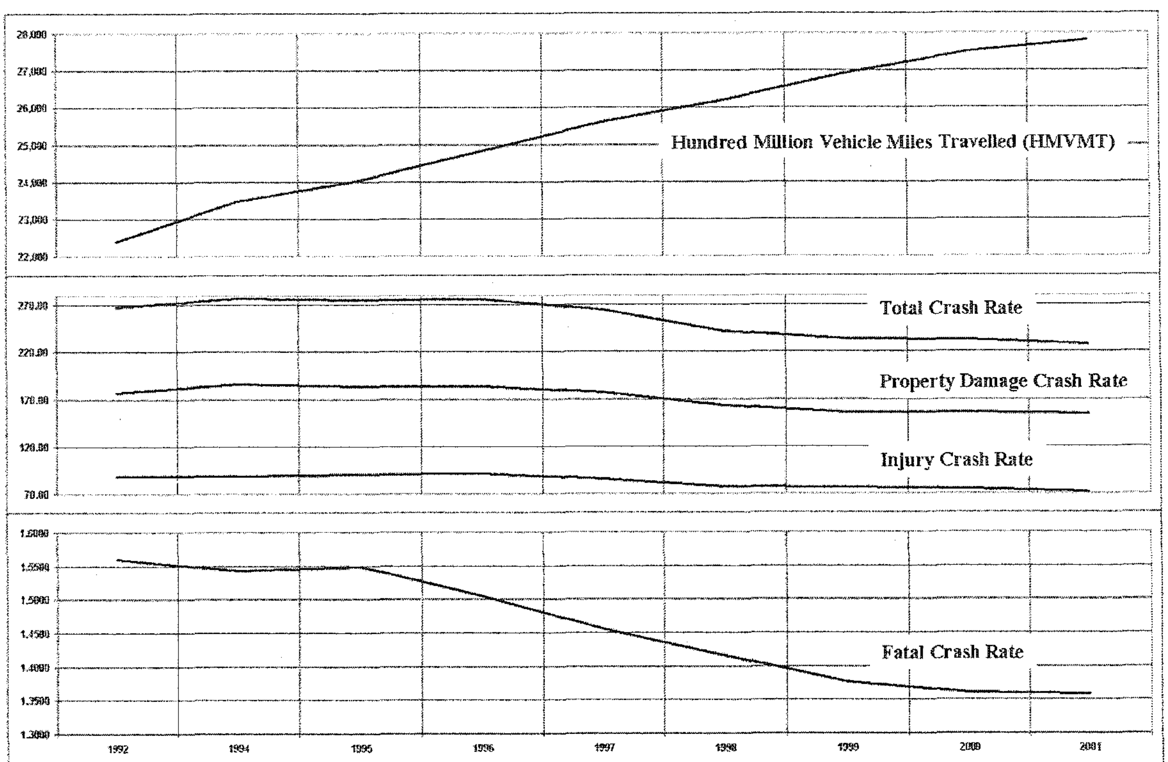


Figure 1.1. National 10-year crash statistics (1992–2001)

In Iowa, the case study for this research, annual fatalities have declined over the past 30 years to around 450. An additional 35,000 Iowans are injured, many seriously or permanently, each year (SMS 1996,1997,1998,1999,2000,2001,2002a,b,c).

As shown in Figure 1.2, coincident with increasing vehicular travel, fatal and injury crash rates have declined over the past 10 years in Iowa. However, the injury and fatal crash rates appear to be leveling off. The Iowa statistics reflect the national problem that, despite decreasing rates, frequencies of death and injury remain consistent or on the increase.

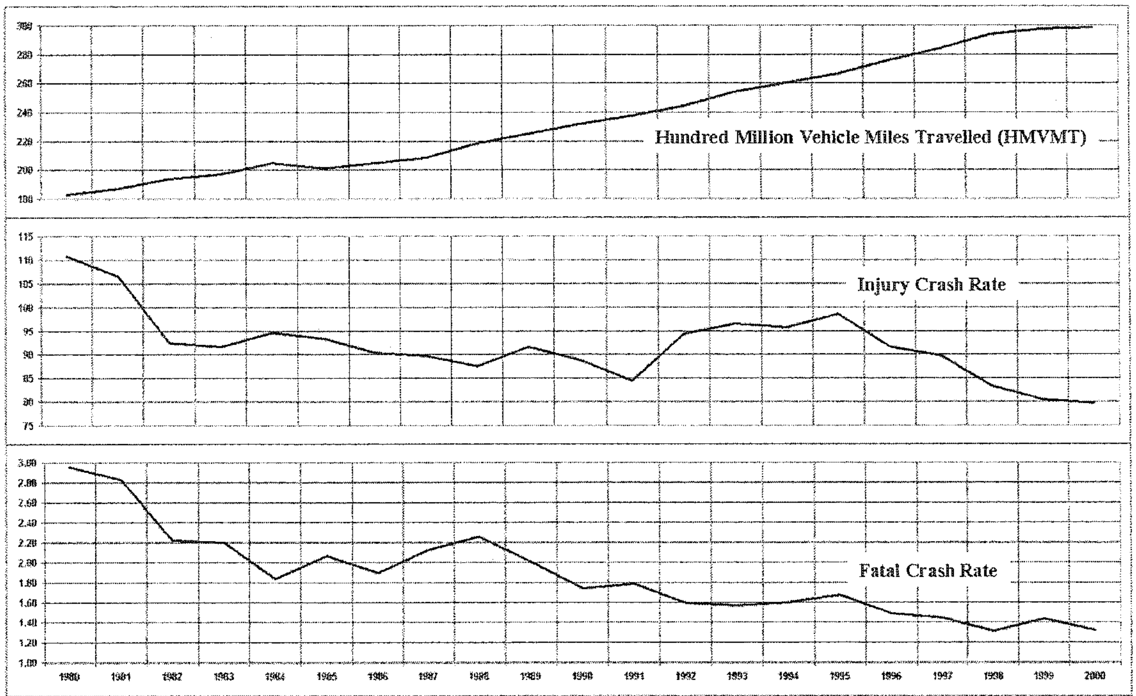


Figure 1.2. Iowa 21-year crash statistics (1980–2000)

Clearly, substantial crash rate reductions have been achieved. The difficulty lies in isolating the source of these gains because a wide variety of safety efforts have occurred over the same time. These efforts include legislative changes, geometric and roadway design improvements, vehicle improvements, and driver education and behavior modification programs. The difficulty in ascertaining the source of safety gains does not mean efforts should be eliminated. Instead, better methods for determining effective strategies should be developed. These strategies should include identification of sites with potential for improvement and the most beneficial response(s) for each deficiency. Targeting sites that have no potential for improvement wastes resources.

Past Safety Improvement Candidate Location Methods

States have traditionally developed SICL lists to identify candidate improvement sites. Past versions have had limitations, primarily with regression to the mean (RTM) and failure to identify "sites with promise (SWiPs)" (Hauer 1996; Hauer et al. 2002b; ITE 1999; MRI 2002a,b,c,d,e,f,g, 2003a,b,c,d,e). RTM is an oft-cited problem with previous methods that tends to overestimate the safety effect of a treatment. SWiPs are sites that have the most potential for improvement and to provide the most benefit. The methods used to generate these lists should therefore be reconsidered, beginning with a review of the historical origins and purpose of the lists.

History

In the 1970s, states were required to "develop and implement, on a continuing basis, a highway safety improvement program with the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on all highways" (FHWA 1979). Identification of "hazardous locations and elements" (Zegeer 1986) or "sites with potential safety problems" (TRB 2000) was an important part of meeting the requirement. This culminated in contributing factor analysis and assessment and selection of the most appropriate countermeasures (TRB 2000). Priority projects, based on some form of economic analysis, were to be identified (Zegeer 1986). Depending on available resources, these projects were to be implemented and later evaluated for effectiveness (TRB 2000).

To facilitate the implementation, a federal Hazard Elimination Program (HEP) was initiated through a series of highway safety acts, culminating in the 1978 Highway Safety Act (Zegeer 1986). From this, many states developed Hazard Evaluation Systems (HES) that implemented the HEP. To supplement the state HES, most states use some type of SICL method to identify "hazardous locations" or "sites with potential safety problems" (ITE 1999; SEMCOG 1997; Zegeer 1986,2001). Some SICL methodologies had existed prior to the federal mandate, and some were developed after (Hallmark et al. 2002; Hauer 1984,1996; Higle et al. 1988,1989; HRGreen 2001; Hunter et al. 1978; ITE 1999; Janson et al. 1998; Pal and Sinha 1998; Perkins and Thompson 1983; Renshaw and Carter 1980; Sinha et al. 1981; Souleyrette et al. 2001; Stokes and Mutabazi 1996; Tarko 1996,1997; TAS 1997,2002; TRB 1975,2001b). Most SICL methods produce "ranking lists" which are then used to direct engineering studies. For a lengthier discussion of SICL methods, see Appendix A.

In Iowa, two programs use the results of the Iowa SICL list process: the Hazard Elimination System (HES) and the Traffic Safety Improvement Program (TSIP) (SMS 2002a,b). Despite the fact that the Iowa SICL was developed primarily for use with the HES, TSIP uses it more often. HES only funds relatively large projects each year while TSIP sponsors many smaller projects. Other states have similar programs.

Limitations

Typically, a list of candidate improvement locations is generated using some combination of crash frequency, rate, and loss (SMS 2002a,b; TAS 1997,2002). (See Appendix B for Iowa's top 500 lists.) A variety of classical statistical techniques are applied, some very simple, others more complex. Most have the Poisson distribution as a base. The simpler methods accept de facto that more crashes, higher rate, or greater loss equate to potential for improvement. This is a common misconception. More complex methods include a measure of statistical control by ranking only sites that meet a certain threshold, usually two standard deviations above average. These methods at least consider the concept that improvement potential is measured by deviance from the mean.

Simple methods, which produce only lists, suffer from a lack of flexibility. Because no indication of potential countermeasures is provided, each discipline (engineering, enforcement, education, and emergency response) examines the top sites, determined through whichever prioritization scheme is preferred. Each identified site is assessed for possible remedial measures (e.g., geometric changes, increased enforcement, public education campaigns) prior to resource allocation. This process is time-intensive and may not target sites with the most potential for improvement. In addition, coordination is not facilitated when countermeasures from multiple disciplines are warranted.

Past SICL methodologies rank primarily on historical crash data, using volume for rate calculations. These methodologies have no mechanism to include past improvements, past rankings, or analyst input. Other than analyst or engineering knowledge of sites, no mechanism for site characteristics is typically included. Assessment of improvements is a separate step, which is often neglected. Therefore, improved sites may reappear on the list with no knowledge gained as to effectiveness (or ineffectiveness).

Related to this, past SICL methods do not provide indicators of deficiencies. They merely rank sites, providing no relationships between sites. Instead, the analyst must provide all knowledge of comparisons and insight into potential countermeasures. Significant staff time must again be devoted to provide assessment, limiting the number of sites that can be considered and thus potentially missing sites with more promise.

The statistical bases for past SICL methods have also been questioned, primarily with respect to their inability to account for regression-to-the-mean (RTM) (Box et al. 1970; Harwood et al. 2002; Hauer 1986,1996a,b,c; Hauer and Persaud 1987; Hauer et al. 1986,1988,2002a; Higle and Hecht 1989; Higle and Witkowski 1988; HSIS 2002; ITE 1999; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e; Parker 1991; Persaud 1988a,b; Persaud and Hauer 1984; Raju et al. 1998; Schluter et al. 1997; Thomas 2001; TRB 1989,2001b). RTM results from the assumption that prior crash frequency is an unbiased estimate of future crashes. Elimination of RTM is important when crash history is connected to safety estimation. Many have tried variations that either alter the statistical basis or increase the years used for analysis. Neither mitigates the problem of RTM completely. In addition, many have questioned the use of the Poisson distribution, promoting the negative binomial instead. This is primarily due to overdispersion often encountered in crash statistics, which is not accounted for by the equal mean and variance of the Poisson distribution.

The traffic safety paradigm is shifting from a focus on reducing frequency to one of limiting severity. Because of flattening crash rate reduction trends and continued increases in deaths and injuries, the effects of past efforts seem to have reached maturity. Therefore, the methods for identifying candidate improvement locations should be revisited (ITE 1999).

Fortunately, development of SICL methods has been ongoing. The latest addition to this continued improvement is the Bayesian philosophy. Fundamentally different from classical statistics, the Bayesian philosophy combines prior (e.g., engineering evaluation) and current (e.g., literature findings, data) knowledge to obtain posterior (e.g., expected crashes) knowledge (Melcher et al. 2001). Bayesian formalism allows adjustment of analyses based on external data, such as expert opinion. The results of Bayesian analysis have considerable interpretative advantages over classical statistics, most prominently providing indication of the most likely value. Classical confidence intervals only produce a probability that the value lies somewhere in a range. Bayesian developments within traffic safety have focused on empirical Bayesian methods, but hierarchical Bayesian methods have also been explored recently (Davis and Yang 2001; Melcher et al. 2001). Both merit further examination.

Empirical Bayes

For over 20 years, empirical Bayesian has been proposed as an alternative that addresses many of the shortcomings of past methods (Hauer 1986, 1996a,b,c; Hauer et al. 1986, 1987, 1988, 2002a,b; Higle and Hecht 1989; Higle and Witkowski 1988; ITE 1999; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e; Pendleton et al. 1991; Persaud 1988a,b; Persaud and Hauer 1984; Saccomanno et al. 2001; TRB 2001b). Most notably, EB is often cited as solving the problem of RTM. EB provides unbiased safety performance estimates by combining observed and expected crash frequencies. It does this by pooling information from like sites to obtain individual site estimates. These estimates facilitate identification of sites where improvements can result in substantial accident reduction – that is, sites most likely to benefit from improvement. EB also increases confidence in estimates and provides information on the relative safety of ranked sites.

The EB approach can be used for SICL list development (Hauer 1996). To accomplish this, first a multivariate model is fit to a reference population of like sites. The distribution of means for this reference population is obtained and a cutoff mean is selected to determine sites deserving further attention. Next, the site being examined undergoes similar examination and its mean is obtained. Finally, if the probability that this site mean is greater than the cutoff is large, the site deserves further examination (Hauer 1996).

EB promotes the use of many years of data to identify and rank sites and presents advancement beyond traditional procedures (ITE 1999). However, according to ITE, the method is "complex and not ready for widespread implementation". Despite this, EB has recently risen to the forefront of highway safety systems development (Hauer et al. 2002a,b; MRI 2002a,b,c,d,e,f,g,2003a,b,c,d, e) and is being widely implemented, at least at the national level. Despite more than 20 years of EB development, less than 15 states are involved in the current effort (MRI 2002a).

Safety performance functions (SPFs) are used by EB to estimate the change in crash frequency that would have happened at an improved site had nothing been done (MRI 2002c,f,2003b,e). SPFs are used in EB to smooth random fluctuation in crash counts when estimating expected crash frequency at a specific intersection (Hauer et al. 2002a,b; Kononov and Janson 2002; MRI 2002c,f,2003b,e; Persaud et al. 2002; Tarko et al. 1998,1999) and reduce the Bayesian reflection of uncertainty in values to point estimates. SPFs are developed from a set of reference sites that must be similar to the improved site. Determination of variables used to define similarity requires a large database of reference sites for each site categorization (ITE 1999). Some have indicated that calibration of these models is complex (ITE 1999; Persaud et al. 2002). These difficulties are reflected in the numerous recent requests for proposals (RFPs) announced by the Federal Highway Administration (FHWA) for development of SPFs.

Hierarchical Bayes

When EB methods for traffic safety were developed 20 years ago, hierarchical Bayesian methods were difficult to implement (Carlin and Louis 2000; Congdon 2001; Gelman et al. 1998; Gilks et al. 1996). With the advent of low-cost, fast computers and development of statistical sampling techniques, hierarchical Bayesian methods may now be explored. These methods avoid some disadvantages of EB (e.g., SPFs and need for reference sites) while maintaining benefits.

Hierarchical Bayesian models treat all variables and parameters as random. As none of the parameters are estimated, there is no need for development and calibration of a priori functions and factors. Also, site characteristic data can be incorporated more easily. Through incorporation of additional data, explicit identification of important causal relationships between site features and safety performance is facilitated. A hierarchical Bayesian approach allows the site data to influence the results, modified by previous site characteristic knowledge (e.g., crashes, geometrics, controls).

Implementation of hierarchical Bayes involves calculations of functions that are often intractable (Gilks et al. 1996). However, statistical sampling techniques have overcome this limitation. A commonly used family of sampling techniques are Markov Chain–Monte Carlo (MCMC) methods.

These methods permit samples to be drawn from the posterior distributions (the result of Bayes' theorem), which are the bases for expected value determination.

Like EB, hierarchical Bayes also addresses the problem of RTM. The combination of observed and expected frequencies provides unbiased estimates of site safety performance. Pooling of information from like sites is done within the framework of the data and model, without a priori categorization. Sites with promise can be easily identified after analysis using the known features of sites. Multiple site categories can be represented simultaneously. Assessment of potential site improvements is therefore automatic, without the need for specialized models.

Hierarchical Bayesian results facilitate ranking according to the difference between expected and observed crash frequencies. In addition, a measure of uncertainty about each rank can be incorporated. This allows determination of the relative confidence in each site's rank, facilitating identification of natural site groupings by potential for improvement. These groupings can be extremely beneficial for determining sites that should be further examined and potentially improved.

In addition to rankings, hierarchical Bayes provides distributions of expected crash frequencies for individual sites and for site groupings (e.g., signalized intersections). These distributions may be used much the same way as the uncertainty about rankings. Individual sites can be compared and definitive statements can be made regarding the probability of one site being worse than another.

Hierarchical Bayes is not prevalent in traffic safety; additional development would be required. However, some or all of the work underway for EB implementation leads naturally into hierarchical Bayes implementation. The model forms developed as part of EB could be extended to hierarchical Bayesian models. For example, SPFs could be used as prior information should hierarchical Bayes be implemented. The publication of EB should also promote acceptance of hierarchical Bayesian.

Objectives

The proposed statistical basis for this research is Bayes' Theorem, and development of a new SICL method is based on the philosophy engendered by this theorem. Rather than considering many various traffic safety issues, the focus is limited to an engineering perspective, in fact, intersection analysis using a subset of variables and only one year of crash data. This focus on intersections is due to the inherent nature of intersections as locations of traffic conflict (Bared et al. 2003; HRGreen 2001; Ogden 1996), the high percentage of crashes that occur at intersections annually (Bared et al. 2003; Chandra 2002; Ostenson 2003; Persaud and Nguyen 1998), and the prominence of intersections on past Iowa top 200 lists (TAS 2001).

This research has four primary objectives. These are to develop a system that

1. Returns an expected value for each intersection,
2. Enables analysis of the effects of intersection characteristics on safety,
3. Identifies a treatment priority that indicates relative difference between intersections, and
4. Quantifies expected improvements to facilitate economic benefit analysis.

This research only treats a portion of traffic safety issues. Development of a method that could consider of all traffic safety issues remains paramount. Without a combined method, application of countermeasures will remain inefficient due to uncoordinated, discipline-specific efforts. This research creates a framework for future development that can facilitate multidisciplinary cooperation.

Organization

The rest of this dissertation is organized as follows:

Chapter 2 presents past research and literature on: safety improvement candidate location methods and intersection safety analysis. The state-of-the-practice in SICL list development is discussed. Past and present efforts using of Bayes' Theorem, both empirical and hierarchical Bayes, are investigated. Data typically used in intersection analyses are noted and the types of analyses used for intersection safety factors are reviewed.

Chapter 3 explains Bayesian theory by first providing a brief synopsis of Bayesian philosophy. Bayesian theory is then discussed, with explanations of both empirical and hierarchical Bayes, clarifying the differences between each and the advantages and limitations of hierarchical Bayes with respect to both EB and classical statistics.

Chapter 4 defines model terms and describes model development.

Chapter 5 describes the methodology used to achieve the research objectives, from model development and data collection, through statistical software use, development of Bayes posterior distributions, and development of resource allocation examples, to assessment of results and development of conclusions and recommendations.

Chapter 6 presents results of the methodology as described in Chapter 4. The models (initial and final) are described. The data are examined and characterized, including description of dummy variables used. The results from the various statistical methods are presented, including a discussion of comparable statistics. Results from the development of Bayes posterior distributions follow, including expected values, covariate effects, rankings, and predictions.

Chapter 7 discusses and analyses the results and recommends future enhancements.

CHAPTER 2. LITERATURE REVIEW

The research detailed in this document rests upon a long history of research efforts. These past efforts relate to safety improvement candidate location (SICL) development methods, classical and Bayesian analysis approaches, and intersection characteristic and safety analyses. The following sections introduce these past research efforts.

Safety Improvement Candidate Location Development Methods

Methods for determining candidate locations, high hazard locations, or sites with promise enable practitioners to determine which sites to focus limited safety improvement funds on (Traffic Institute 1999). Identification of these locations is a vital component of hazard reduction and safety improvement. Focusing on the locations identified, practitioners can address safety concerns and ultimately reduce crash frequency and/or severity.

The federally mandated Highway Safety Improvement Program (HSIP) requires each state to "develop and implement, on a continuing basis, a highway safety improvement program which has the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on all highways (FHWA 1979)." A comprehensive HSIP consists of three components: planning, implementation, and evaluation (Zegeer 1986).

The planning component should consist of processes that (Zegeer 1986)

1. Collect and maintain data (including crash, traffic, and roadway data),
2. Identify hazardous locations and elements,
3. Conduct engineering studies, and
4. Establish project priorities (i.e., utilize some type of benefit/cost analysis).

Implementation usually involves taking the results of the last two planning components and defining projects, through design and specification. If these projects meet appropriate funding requirements (including benefit/cost requirements) they will then be constructed or implemented.

Evaluation is performed post-construction or implementation to determine the effectiveness of the projects and to improve future HSIP efforts. Evaluation involved some of the same processes as the planning component, namely data collection, identification, and engineering studies.

The crash or hazard mitigation process, as defined by the HSIP, has sometimes been divided into six steps (TRB 2000):

1. Identify sites with potential safety problems.
2. Characterize crash experience.
3. Characterize field conditions.
4. Identify contributing factors and appropriate countermeasures.
5. Assess countermeasures and select most appropriate.
6. Implement countermeasures and evaluate effectiveness.

Step 1 is the same as process 2 of the implementation component; steps 2 through 5 essentially restate processes 3 and 4 from the planning component; and step 6 restates the implementation and evaluation components. Thus, evidence exists supporting the importance of the identification phase to overall safety improvement efforts, whether they are reactive or proactive. In fact, the identification process is the basis, in both listings, for the further processes, in that identification of sites provides analysts and evaluators with a starting point for further study. Without this, they could potentially be faced with the prospect of analyzing and evaluating innumerable sites.

The identification process needs to be as accurate and informative as possible, resulting in a defensible listing of the sites that are "most hazardous" or that have the "most promise" of crash frequency and severity reduction. However, creating an accurate and informative identification process is not simple and efforts are ongoing to improve and enhance the identification process with both reactive and proactive purposes in mind. This fits well with the HSIP requirement of continuing development and implementation of a highway safety program.

State-of-the-practice/state-of-the-art

State-of-the-practice SICL methods are primarily used by public agencies on the state and local levels. Many of them have existed for the past couple decades and have not been updated to reflect recent advances in computing and statistics. However, they perform the base function of an SICL method quite well; they result in a ranking list for consideration by analysts and evaluators.

Though all of these "state-of-the-practice" methods have proven useful, none addresses the identification of high crash locations thoroughly. Appendix A covers each of these state-of-the-practice methods in more detail. In addition to the problems with each stated previously, all the methods ignore a significant majority of the systemwide sites in their analyses. Sites without any crashes in the time period analyzed are routinely ignored. This directs all mitigation measures to a reactive, rather than proactive, role. While consideration of only those sites having a crash history makes direct sense from a crash reduction standpoint, consideration of sites without a crash history is more difficult to justify. Inclusion of sites without a crash history allows for analysis of those factors about the sites that might lend themselves to safety or the lack thereof. To determine the problems on a systematic basis requires much more effort than obtaining crash histories and traffic volume data. To properly analyze sites to determine their deficiencies, a systemwide database containing the relevant attributes must be developed, thereby increasing the level of effort required to create a ranking list.

To mitigate some of the limitations, practitioners and researchers have reviewed a variety of statistical models and distributions. However, scant research related to classical statistical methods for developing candidate locations was found. Most of the research was devoted to analysis of specific countermeasures or topics (e.g., intersections, older drivers, young drivers, injury severity). Classical statistical methods could be further developed for candidate location development. Research related to classical methods is reviewed here.

Taylor and Thompson. In 1977, Taylor and Thompson completed a Federal Highway Administration (FHWA) report related to methods for identifying hazardous locations (Taylor and Thompson 1977a,b,c). Their reports summarized and explained use of various high hazard location methods, including frequency, rate, and severity.

Council et al. In 1980, Council, Reinfurt, Campbell, Roediger, Carroll, Dutt, and Dunham published the results of another FHWA study related to accident research (Council et al. 1980). Though not directly focused on hazardous location identification, this report explains classical statistics in great detail for traffic safety practitioners. The methods explained in this report are applicable to the classical methods of hazardous location identification.

Nicholson. In 1985, Nicholson discussed the fallibility of the "Poisson assumption" with regard to accident counts and identification of high hazard locations (Nicholson 1985). He contends that hazardous location identification has been based primarily on analysis of spatial variance in accident occurrence but that temporal considerations might also be included. His primary point is that the assumptions underlying the Poisson distribution, with respect to crash incidence, might be violated. Instead, practitioners ought to consider alternative distributions, namely the binomial or the negative binomial distributions. He makes the point that the simplicity of implementing Poisson analysis, which previously drove its application, is less relevant with the "widespread availability" of computers "for storing and analyzing accident data."

NCHRP 128. In 1986, Zegeer published the results of a National Cooperative Highway Research Program (NCHRP) project that summarized several methods for identifying hazardous highway elements (Zegeer 1986). This report is primarily designed to educate highway agencies about what types of highway locations are hazardous but might not have experienced crashes. He speaks of "potential for high accident frequency or severity" as opposed to crash history.

Spring et al. In 1987, Spring, Collura, and Shuldiner investigated the use of expert systems for high-hazard location analysis (Spring et al. 1987). They hoped that by automating the analysis of hazardous locations the effectiveness safety operations would be enhanced. They contend that consistent and comprehensive analysis would improve overall safety and efficiency. They then develop a method through which expertise can be incorporated automatically and conclude that this approach appears feasible for performing the location analysis portion.

Spring and Hummer. In 1995, Spring and Hummer addressed the possibility of identifying hazardous highway locations using knowledge-based geographic information systems (GIS) (Spring and Hummer 1995). They mention that the increased capabilities offered by GIS, along with detailed mapping, help "demonstrate the use of engineering knowledge regarding accident causation to identify hazardous locations." They discuss difficulties encountered with applying GIS to the task but clarify that most of the major difficulties were due to data problems or limitations.

SEMCOG. In 1997, the SouthEast Michigan Council of Governments (SEMCOG) published a manual for traffic safety (SEMCOG 1997). One chapter of the manual covers identification of high hazard locations, and many of the typical procedures are detailed, including frequency, rate, and severity.

Nicholson. In 1999, Nicholson examined the use of spatial distributions of accidents for identification of high hazard locations (Nicholson 1999). He suggests that analysis of spatial distributions of accidents will aid in selection of the most appropriate accident reduction program. He also contends that spatial analysis will aid in assessment of effectiveness. He underscores the need for technique for identifying deviations from spatial randomness.

Hallmark et al. In 2002, Hallmark, Basavaraju, and Pawlovich published a report detailing an evaluation of Iowa's current high crash location identification procedure (Hallmark et al. 2002). The goal of the research was to evaluate the effect of fatalities on Iowa's candidate list with a secondary objective of evaluating the weighting scheme used. The results of the research include a shift in the weighting of individual injuries and an increased focus on severity in the final ranking scheme.

Strauss and Elder. In 2003, Strauss and Elder finalized a report related to the spatial analysis of older driver crashes in Iowa (Strauss and Elder 2003). The research focuses on spatial statistical techniques to identify locations of concern for older drivers within the state of Iowa. Using spatial clustering techniques, locations of concern on Iowa's primary highways are identified.

Comparison of classical and Bayesian approaches

In both classical statistical methods and Bayesian approaches, once a model has been assumed and data have been obtained, ordinary least squares (OLS) or maximum likelihood estimators (MLEs) are used to determine model results. Classical and Bayesian methods are similar up to the point of using OLS or MLEs. After that, they diverge.

A main advantage of classical methods is that they are familiar and well developed. The fact that many people are familiar with them results in their common usage and understanding. In addition, familiarity means that more people can use them.

Classical methods have disadvantages as well. As classical models assume that the model is fixed, there is no provision for the data not fitting the analyses. That is, the assumption of a model (e.g., Poisson) locks the analyst into results with regard to Poisson, despite the fact that oftentimes the data do not "fit" the model. In addition, especially in comparison to Bayesian, classical statements of probability are unclear and often misinterpreted (Carlin and Louis 2000). Bayesian probability statements are much more straightforward and unlikely to be misinterpreted. Finally, classical methods do not provide for inclusion of "prior" knowledge. Therefore, knowledge gained from one analysis cannot be used to refine future analyses except for the knowledge gained by the analyst. Bayesian methods, though regarded as more complex, offer far more advantages and potential.

Bayesian approaches

Though Bayes' theorem has existed for roughly 250 years, implementation of the theorem has been limited to simple examples until relatively recently. In traffic safety literature, Bayes' theorem has been mentioned for roughly 25 years. The first implementations used what are called empirical Bayesian (EB) methods. More recently, with the advent of more powerful computers and advanced statistical sampling methods, a complete implementation of Bayes' theorem (i.e., hierarchical Bayes) has become possible. Though widely used for disease mapping and other non-traffic safety applications, hierarchical Bayes has only very recently been used for traffic safety applications. A review of traffic-safety related applications of EB and hierarchical Bayes is present in the following sections.

Empirical Bayes

The empirical Bayesian approach makes use of Bayes' theorem but at the point when distributions are assigned to model parameters and a hierarchical structure is developed, EB assigns estimates to the parameters. These parameters are assumed to be known and the estimates are calculated prior to the analysis using separate parameter estimation analyses. Essentially, EB uses the observed data to estimate the final stage parameters, prior to EB implementation. Over the past 25 years, several traffic safety-related applications have been published.

Persaud and Hauer. In 1984, Persaud and Hauer compared two methods for removing the bias from before-and-after accident studies (Persaud and Hauer 1984). They note that previous papers have shown that simple before-and-after comparisons are biased and that treatments are frequently regarded as more effective than they should be. Instead, they proposed use of the EB approach because it accounts for regression to the mean and, therefore, more correctly estimates the effects of treatments.

Hauer. In 1986, Hauer examined the estimation of expected number of accidents (Hauer 1986). Hauer first shows that regression to the mean does occur from year to year for accident counts at a location. He then details the problems this causes for safety research. Though no specific mention of EB is made, his arguments suggest the need for a methodology such as EB.

Hauer et al. In 1986, Hauer, Lovell, and Persaud published the results of FHWA-sponsored research related to safety effectiveness evaluation techniques (Hauer et al. 1986). Two main questions are addressed: how we learn about safety effects and how we decide what is worthwhile research. The authors contend that there is a need for statistical machinery that ensures unbiased information is obtained and accumulated from study to study. They state that the process of learning is vital so resources should not be wasted on ineffectual countermeasures. They make a strong point that previous methods provide no instrument for learning and may in fact inhibit learning through inconclusive results. They mention EB as an alternative method that can overcome these issues.

Hauer and Persaud. In 1987, Hauer and Persaud applied EB to the estimation of rail-highway grade crossing safety and safety effectiveness of warning devices (Hauer and Persaud 1987). They contend that rail-highway grade crossing safety should be estimated by mixing causal factor information such as volumes, warning devices, and geometry with the accident history. They suggest that information regarding similar sites should be mixed with information about specific sites to further clarify the expected safety of the specific site. They propose EB, implemented using generalized linear models, as a method that can manage this and proceed through an example analysis.

Hauer et al. In 1988, Hauer, Ng, and Lovell estimate the safety at signalized intersections using EB as implemented using generalized linear models (Hauer et al. 1988). Insights gained through this analysis include the idea that "logically sound" models require collision frequency to be related to their associated volumes, that collisions ought be categorized based on vehicle movement and not initial impact, and that the relationships between collision frequency and flows are not entirely expected. They state that though traditional analyses that do not categorize collisions by flow are simple, they do not satisfy engineering requirements for cause and effect relationships.

Persaud. In 1988, Persaud used EB to examine the effect of traffic signals on safety (Persaud 1988). In a review of often-cited studies on traffic signal installation safety impacts, he finds the studies deficient with respect to methods and inferences obtained from results. He identifies two common pitfalls: regression to the mean and incorrect inferences from cross-section studies. He acknowledges that the safety effect is impacted by many factors and proposes that EB may be used to combine these factors and correct for the common pitfalls.

Higle and Witkowski. In 1988, Higle and Witkowski discussed the possibility of using Bayesian methods for identification of hazardous locations (Higle and Witkowski 1988). They briefly review a couple common methods for identification of hazardous locations, including rate and rate-quality control. They note that it is common knowledge that historical accident data do not reflect long-term accident characteristics due to random variations (e.g., regression to the mean). They note that researchers have been promoting Bayesian methods to overcome limitations of classical methods. Their stated motivation for use of Bayesian methods is the desire to treat actual accident rate at a particular location as random and use a combination of regional characteristics and accident history at the location to determine the probability of site hazardousness. They assert that Bayesian methods better utilize the available information. They then proceed by comparing two classical methods (based on rate and rate-quality control) to two analogous Bayesian methods. Their conclusions note numerous advantages to the Bayesian methods. Attached discussion responses indicate less certainty in their results while still agreeing that Bayesian methods may be superior.

Higle and Hecht. In 1989, Higle and Hecht revisit the use of Bayesian methods for identification of hazardous locations (Higle and Hecht 1989). Building on the research of Higle and Witkowski, they continue their comparison of classical methods with Bayesian methods. Their results indicate that the rate-quality technique is virtually indistinguishable from the Bayesian techniques and is more computationally straightforward.

Pendleton et al. In 1991, Pendleton, Gonzalez, and Duarte published two reports resulting from FHWA-sponsored research into EB methods (Pendleton 1991; Pendleton et al. 1991). This research resulted in a report explaining the justification for use of EB and a general methodology for its use. In addition, software was developed for implementing the EB approach and a manual for its use was written. The examples of use included in the report illustrate use of the software for ranking of counties.

Davis and Gao. In 1993, Davis and Gao used EB to support induced exposure analyses of traffic accident data (Davis and Gao 1993). Induced exposure methods are used to estimate relative accident risk of driver subgroups when group exposure measures are unavailable. Using EB, they develop a method to identify sites with significantly higher accident rates for particular driver subgroups.

Hauer. In 1996, Hauer submitted a paper concerning the detection of safety deterioration using accident counts (Hauer 1996a). He develops a workable procedure to detect sites where mean frequency increased more than what could be attributed to traffic increases or general trends. He clarifies that both steady, gradual deterioration and sudden increases are both of concern. By applying his procedure to many sites, the detected sites could be examined in greater detail. EB may be applied to the detection of the sites.

Hauer. In 1996, Hauer explained the use of EB for identifying sites with promise (SWiPs) (Hauer 1996b). He clarifies that SWiPs are not just sites where crash frequency is high but rather sites that are performing worse than expected given site characteristics. He critiques four standard ranking procedures (i.e., frequency, rate, rate-quality control, and frequency and rate) and compares them to EB. Illustrating the use of EB for the task of identifying and ranking sites, he illustrates that EB has several advantages over the other methods, one being the ability to include more in the analysis beyond crash history.

Hauer. In 1996, Hauer examined the application of statistical tests of differences between expected accident frequencies (Hauer 1996c). He explains several common statistical hypothesis tests, providing information as to when each is appropriate to improve use of the tests. He mentions that, in monitoring safety, detection of sites whose safety has deteriorated is of interest. If a site's safety has deteriorated, it is worth examining in more detail. EB may be applied to the testing of the hypotheses.

ITE. In 1999, the Institute of Transportation Engineers (ITE) published a report summarizing statistical evaluation used in traffic safety studies (ITE 1999). The report introduces the topic by stating that "the application of appropriate statistical analysis techniques is essential for the proper evaluation of traffic safety studies, traffic safety research, and countermeasure selection." To underscore this statement, the report adds that traffic accident reductions have been hampered by both inadequate and conflicting statistical results. The authors then focus on identification of "high hazardous" sites and mention that the major problem is reliance on minimal years of data and resulting susceptibility to random fluctuations. They introduce Hauer's SWiPs concept. Statistical techniques for site identification include several classical methods (i.e., frequency, rate, rate and number, rate quality control, and accident severity) and the EB approach. They introduce the EB requirement for homogenous reference groups and detail two EB approaches, Hauer's method and the extended EB method. They clarify that Hauer's method is new and innovative, requiring further testing and refinement. The extended EB method adds the ability to model covariates (e.g., roadway characteristics that might affect highway safety). Its advantages include the ability to model covariates. However, determining variables that define homogeneous sections is "challenging" using this method. A software tool developed for implementation of the extended EB method "requires more work."

CHSIM. In 2000, FHWA began an effort to develop Comprehensive Highway Safety Improvement Model (CHSIM) (MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e). CHSIM is a software development effort for creating a user-friendly method of safety resource allocation based on EB. Renamed SafetyAnalyst, the software will have four modules that cover six steps of the safety prioritization and evaluation process. The modules include network screening, diagnostics and countermeasure evaluation, economic appraisal and priority ranking, and countermeasure evaluation. Both the network screening and countermeasure evaluation are based on the EB approach. Network screening, which is most relevant to this research, involves the use of safety performance functions (SPFs) to predict accident frequencies for sites. The purpose of network screening is use data to review the road network and prioritize sites based on the promise of those sites for effective improvement. Network screening seeks to identify sites for further detailed review, limiting the costly, time-intensive detailed study to a subset of possible sites.

NCHRP Synthesis 295. In 2001, the Transportation Research Board (TRB) published an NCHRP synthesis of highway practice related to statistical methods used in highway safety analysis (TRB 2001). This synthesis reported analyses completed using the EB approach. The publication lists several research efforts that have used the EB approach and unequivocally endorse its use. Use of EB for the Interactive Highway Safety Design Module (IHSDM) and planned use for the CHSIM are mentioned. Both IHSDM and CHSIM are FHWA software development efforts for design and evaluation of highway systems. The synthesis also mentions the ongoing development of a Highway Safety Manual (HSM), which will be similar to the current Highway Capacity Manual (HCM). Given the use of EB for IHSDM and CHSIM and its current national focus, EB will probably figure prominently in the HSM.

Saccomanno et al. In 2001, Saccomanno, Grosst, Green, and Mehmood used EB to identify black spots in southern Italy (Saccomanno et al. 2001). They state that to effectively use available funds for safety improvements, high priority locations must first be located. The research compares the use of multivariate Poisson regression to EB methods. They find that EB yields fewer black spot locations than Poisson regression and, as safety countermeasures are best applied at the black spots, EB use could result in significant cost savings. In their application of EB they use the negative binomial (NB) distribution, which is "more general than the Poisson" and doesn't assume equal mean and variance.

Hauer et al. In 2002, Hauer, Kononov, Allery, and Griffith reported on the concept of screening road networks for SWiPs (Hauer et al. 2002b). For site safety improvement, network screening occurs first and produces a list of sites that may be ranked for further detailed analysis. The purpose of screening is to produce a manageable number of sites that undergo further detailed engineering examination. They describe a variety of classical methods of screening, pointing out deficiencies and inefficiencies. They propose an EB approach to screening, explaining the benefits of the approach, and clarifying that cost effectiveness is the primary goal of screening methods. They mention that EB will be used with CHSIM.

Hauer et al. In 2002, Hauer, Harwood, Council, and Griffith published a tutorial explaining the EB method for estimating safety (Hauer et al. 2002a). They point out that EB addresses two safety estimation problems: increased precision of estimation and correction of the regression to the mean. They state that, because EB is used in IHSDM and being developed for use with CHSIM, the time has come for EB to become the standard of professional practice. By using the accident record of a site and the frequency expected at similar sites, EB produces better estimates of safety performance.

Hierarchical Bayes

Though the EB approach improves on classical methods of candidate site identification or network screening, it remains a simplification of the hierarchical Bayes method. Hierarchical Bayes is a purer use of Bayes' theorem, retaining all the benefits of the EB approach but eliminating the need for a priori calculation of safety performance functions. This a priori development can be time-intensive, costly, and inadequate for all situations. Hierarchical Bayes frees the analyst from having to categorize sites and allows the data to directly influence the results to the degree that uncertainty is indicated.

There are few references in the transportation safety field related to hierarchical Bayesian methods. Very few relate to hazardous location candidate list development. However, many applications of hierarchical Bayesian methods exist outside traffic safety. A review of the available research follows.

Breslow and Clayton. In 1993, Breslow and Clayton applied Bayesian techniques to estimation of generalized linear mixed models (GLMM) (Breslow and Clayton 1993). They begin by noting that statistical approaches to overdispersion, correlation errors, estimation of shrinkage, and regression relationship smoothing can be encompassed within a GLMM framework. They further explain that Bayesian procedures, simplified by sampling techniques (e.g., Gibbs sampling), remove the problems of "irreducibly high-dimensional integrals." They compare Bayesian methods with a couple other alternatives and conclude that Bayesian methods are superior. Briefly mentioning EB, they note that it has a "failure to account for the contribution of the estimated variance components when assessing the uncertainty in both random and fixed effects."

Davis and Guan. In 1996, Davis and Guan used Bayesian theory to identify high-risk intersections for older drivers (Davis and Guan 1996). Combining hierarchical Bayes methods with an induced exposure model and using Gibbs sampling, they identified intersections where older drivers are at higher risk than other age groups. They comment that computation time for the computer they utilized was excessive but that computer advances should reduce the time and enable larger studies.

Schluter et al. In 1997, Schluter, Deely, and Nicholson note that "few methods exist that can quantitatively, accurately, and easily discriminate between sites that commonly have small and variable observation count periods" (Schluter et al. 1997). They note that the hierarchical Bayesian model "embodies all these advantages." They use a relatively small sample of 35 sites identified using "previously published fatality accident data." These data include fatality crash data and some information about changes in site layout or form of control taken from an earlier study by Nicholson. Using this information and incorporating "expert knowledge," they develop a model using the Poisson assumption and a conjugate gamma prior. Finally, they discuss three strategies for ranking and selection and outline a procedure for determine how much worse a site is. Though their work makes a good argument for the use of hierarchical Bayesian models, it fails in that it doesn't carry the use of Bayes far enough. The lack of data, both in numbers of sites and in amount of information about each site, fails to demonstrate the applicability and potential of the Bayesian model.

Raju et al. In 1998, Raju, Souleyrette, and Maze used an integrated Bayesian forecasting and dynamic modeling approach to analyze the impact of the 65 mph speed limit on Iowa's rural interstate highways (Raju 1998). To create this approach, they combined time series with Bayesian analysis. Their conclusions include the statement that "the Bayesian approach produced forecasts with uncertainties that are lower than those from the standard time series model."

Davis. In 2000, Davis used hierarchical Bayes to estimate traffic accident rates while accounting for traffic-volume estimation error (Davis 2000). Using Gibbs sampling, he uses Bayes to explicitly account for traffic estimation error. Previous methods had had to be simple and were inadequate for the demands of the analysis. His method allows for greater flexibility and complexity in the model. He advocates future use of Gibbs for this purpose.

Davis and Yang. In 2001, Davis and Yang used a Gibbs sampling application of Bayesian methods to identify high-risk intersections for older drivers (Davis and Yang 2001). They combine hierarchical Bayes methods with an induced exposure model in order to identify intersections with overrepresentation of risk for the older driver subgroup. They note the impending retirement of the baby boom generation and its guaranteed impact on traffic safety. They detail their application of hierarchical Bayes for this problem, concluding that the method is sound but that current application to large data sets might be infeasible due to computation time required. However, they mention that computer improvements should make the application of hierarchical Bayesian more feasible in the near future.

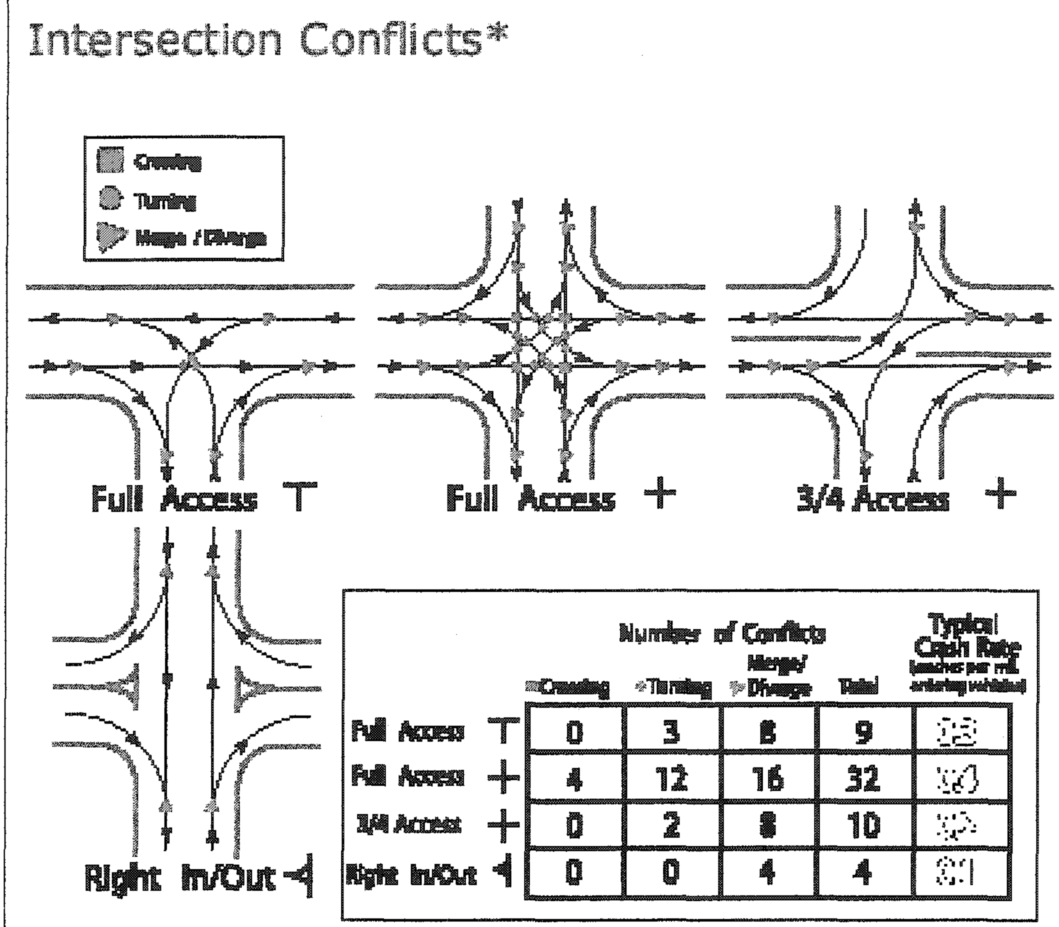
Melcher et al. In 2001, Melcher, Dixon, Washington, and Hu assessed the feasibility of "subjective" engineering assessments of road safety improvements using Bayesian methods (Melcher et al. 2001). They assert that regional safety program managers are challenged by the need to reduce impacts (i.e., fatalities, injuries, cost) of crashes while dealing with large perceived need, limited budgets, and uncertainty of countermeasure effectiveness. They mention that EB applications have used data to obtain prior information. Their research focuses on subjective sources for obtaining the prior information. They detail a method for determining crash modification factors (CMFs), which provide an assessment of the effectiveness of particular countermeasures. They list several differences between classical and Bayesian analyses. They clarify that Bayesian analyses have several advantages, most prominently an interpretive advantage for statistical inference.

Intersections

The following review of intersection literature will focus on three topics. First, a section discussing the importance of intersection safety study is presented. An assessment and summarization of the important features of intersections from a safety perspective follows. Finally, topics and analytical methods related to intersection safety are reviewed.

Intersection safety background

To motivate study of intersections, let us first consider that, by their very nature, intersections are locations of potential conflict (Ogden 1996; AASHTO 1997; HRGreen 2001; Rosenbaum et al. 1982; TRB 2001a,2002a,b). This maxim applies to all intersection types; however, only highway motor vehicle intersections are considered here. For these intersections, the number of conflict points depends on the type of intersection, as shown in Figure 2.1. Analysis of different intersection



	Number of Conflicts: Crossing	Turning	Merge/ Diverge	Total	Typical Crash Rate (crashes per mil. entering vehicles)
Full Access T	0	3	6	9	[illegible]
Full Access +	4	12	16	32	[illegible]
3/4 Access +	0	2	8	10	[illegible]
Right In/Out	0	0	4	4	[illegible]

*From Minnesota Department of Transportation, *Traffic Safety Fundamentals Handbook.*

Figure 2.1. Intersection conflict points (HRGreen 2001)

configurations can be used to discover how to reduce crashes and minimize crash severities while simultaneously maintaining operation characteristics.

Because intersections are a natural location for conflicts, a significant portion of traffic crashes occurs at intersections (AASHTO 1997; HRGreen 2001; Ogden 1996; Rosenbaum et al. 1982; TRB 2001a,2002a,b). Intersection crashes represent more than 50% of urban crashes and 30% of rural crashes (TRB 2001a,2002a,b). In 2001, almost 9,000 fatalities and 1.5 million injuries occurred at intersections (Bared et al. 2003). Every year, nearly 3 million intersection-related crashes occur (Chandra 2002). FHWA has an objective to reduce intersection fatalities by 10% by 2007 (Bared et al. 2003).

From a safety perspective, several intersection characteristics concern practitioners. For decades, certain characteristics of intersections have been identified in the literature as affecting safety. Many research reports cover intersection safety, both the features affecting it and the crash reduction potential of each. In addition, there is a great deal of research related to using statistical methods to investigate safety at intersections.

Intersection safety features

Intersection safety features have been researched frequently over the past decades. Because intersections are natural locations of potential conflict, crashes at these locations are frequent. Researchers have attempted to determine which intersection features are critical to improving safety and reducing the potential for harm. A brief review of several studies related to intersection features follows.

David and Norman. In 1975, David and Norman produced a three-volume research report relating traffic crashes to geometric and traffic features of intersections (David and Norman 1975a,b,c). The research, based on a database of 558 intersections with 4,372 crashes over three years, examined the relationship between intersection geometry, traffic, and crash rates for intersection groups with common design features. Data collected for the research included physical and demographic data, numbers of registered vehicles, licensed drivers by age and sex, vehicle miles traveled, and study-area crash characteristics.

David and Norman considered the physical and traffic-control features of the intersection and 200 feet along each approach, operational data, and crash characteristics. Data elements collected for each are shown in Table 2.1.

Table 2.1. Geometry, operational, and crash data

Category	Element
Physical and traffic-control features	• divider usage, both raised and painted • number of lanes and width • shoulder use, condition, and width • pavement type and condition • illumination and visual obstructions • number and types of signals, signs, and pavement markings

Table 2.1. (continued)

Category	Element
Operational data	• traffic signal timing and phasing • traffic volume • speed limits • bicycle and bus routing
Crash characteristics	• injuries • severity • collision type • time of day • day of week

David and Norman further categorized the data into four divisions: general, geometry, traffic controls, and traffic volume and speeds. The data elements for each division are shown in Table 2.2.

Table 2.2. Intersection characteristic data

Category	Element
General	• Type of intersection • Lanes • Roadways • Lane use • Illumination • Time of day • Day of week
Geometry	• Through width • Turning lanes • Shoulders • Dividers and curbing • Obstructions and alignment • Hazards
Traffic control	• Signalization • Signs and markings • Lane delineation • Parking
Traffic volume and speeds	• Crashes by ADT • Conflicts • Volume ration • Speeds • Vehicles in traffic

Further data collection and variable details were provided in the third volume of the report. These data were gathered for 558 intersections, both T-type and cross-type intersections. These intersections were chosen because of significant crash histories in conjunction with certain specific characteristics related to the data collect above. Finally, the research concluded that six intersection design features were demonstrably accident related. These features included sight-distance obstruction, street-name signs, left-turn storage lanes, raised marker delineation, bus-loading zones, and multiphase signalization.

Faulkner and Eaton. In 1977, Faulkner and Eaton investigated the application of the location sampling technique to crash investigation and prevention for rural crossroads (Faulkner and Eaton 1977). They contend a successful demonstration of this technique to diagnosing and treating a particular type of site with higher accident risk, such as straight-through rural crossroads. Using the installation of traffic islands along with appropriate signing is shown to decrease crashes 49% over four years, mainly through elimination of minor road overrun crashes.

Rosenbaum et al. 1982, Rosenbaum, Pinnel, and Kemper wrote a synthesis report related to traffic control and roadway elements (Rosenbaum et al. 1982). In a chapter on intersections, they define an "intersectional area" that includes not only the intersection proper but also the area along each approach where maneuvers such as lane changing and deceleration, related to the intersection, take place. They note that, although intersections make up a small portion of the network, roughly half of urban crashes and a quarter of rural crashes occur at intersections. They cite data that indicate intersection crash numbers are rising faster than crashes in other locations, that roughly 90% of intersection crashes involve multiple vehicles, and one-third of fatal urban intersection crashes involve pedestrian death. They stress that safety efforts should be focused on intersections for these reasons.

The rest of the chapter concentrates on a 1979 Stanford Research Institute study that determined that 15% of all crashes under study related to the physical environment or traffic control and enforcement. The study comments on the now well-known statistical phenomenon, "regression of the mean," and notes that it can bias results, skewing perceived benefits of a study. In addition to "regression of the mean," three other cautions are mentioned:

1. Past research tended to reduce the expected effects of a countermeasure to a single-valued estimate. This value can guide or serve as a benchmark for comparison but obfuscates potential variations resulting from different applications.
2. Past research was conducted on a limited scale, resulting in the need for risky extrapolations.

3. Countermeasure effectiveness is highly dependent on site characteristics, the target driving population, and other existent complementary countermeasures.

The research makes a couple recommendations, the first being to focus on severity reductions rather than frequency reductions and the second to accelerate research on intersection geometry and countermeasures to reduce crash frequency. The research includes a database of 558 intersections in the San Francisco area covering a three-year period. This database is the same database that David and Norman, of the Stanford Research Institute, reported on in 1975. Immediately it is apparent that great benefits can be realized from an excellent database, allowing multiple research efforts using the same database. The results they mention are categorized as shown in Table 2.3.

Table 2.3. Intersection categories

Intersectional geometry	Street signs
Visibility and sight distance	Bus routes
Lighting	Channelization and left turn lanes
Pavement surface condition	Sign control
Fixed objects	Traffic signal control

Subset categories within this last group include those shown in Table 2.4.

Table 2.4. Traffic signal control subcategories

Urban intersection traffic control	Flashing traffic signal operation
Yellow indication	Right turn on red
All-red intervals	Flashing beacons

Channelization of intersections resulted in 32.4% reduction in all crash types; personal injury crashes decreased over 50%; and an average benefit/cost ratio of 2.31 was realized. Raised barrier left turn lanes proved significantly more effective than painted left turn lanes. Evaluating Federal Highway Safety Program projects indicated that, of 34 different improvement types, intersection sight distance enhancement was most cost effective, with a benefit/cost ratio of five. In this particular 558-intersection study, sight distance improvement, limiting ground obstructions to 2.5 feet and overhead obstructions to a minimum of 8 feet, resulted in the greatest percentage reduction in crashes. Intersections without sight distance limitations had significantly lower crash rates and severity than those with limited sight distance. With regard to intersection illumination, the researchers found that the addition of lighting reduced the average night crash rate.

California established a warrant, and at intersections meeting the warrant the average night crash rate was reduced from 4.59 prior to illumination to 1.28 after lighting was added, a 72% reduction. Illuminating intersections not meeting warrants reduced crash rates from 1.49 to 0.92, or 38%.

The Rosenbaum et al. synthesis also discusses the following studies:

A 1976 Iowa DOT analysis of the impact of rural intersection illumination concluded that the average night crash rate reduction achieved was 51.9%. However, the 51.9% might be somewhat inflated as daytime crash rates at those locations fell 12.7% during the same period.

An analysis of rural Illinois intersections, some lighted and some not, found that night crash rates were 45% less at lighted intersections. In addition, the ratio of nighttime crashes to total crashes was 22% less at lighted intersections. Furthermore, another conclusion of the study was that channelization added to this reduction.

The results of these intersection studies indicate that lighting significantly improves driving performance and driver detection and recognition of an intersection, signing and delineation had only marginal effects, and new pavement markings had no effect. The safety effects of sign control at intersections include the following: yield signs at low volume isolated urban intersections reduce crashes effectively; four-way stop control at intersections with relatively equal approach traffic volumes significantly reduce crashes; and four-way stop control at intersections with variant approach traffic volumes increases crashes.

A Philadelphia conversion of 222 intersections from two-way stop control to four-way stop control during the 1970s produced the following results: 75% of conversions improved conditions, regardless of prior crash rate; 50% of low crash rate sites that were converted resulted in increases; six of seven sites with relatively high crash rates experienced crash reductions; total crashes decreased 55% overall after conversion; personal injury crashes decreased 81%; right-angle collisions decreased 83%; and pedestrian injury crashes decreased 83%.

A 1976 study of speed and stop sign observance in Troy, Michigan, suggests that the common public belief that stop signs reduce speeds may be false. The study concluded that compliance was poor.

Related to traffic signals, the synthesis determined that properly located and operated signals typically reduce right-angle crashes while simultaneously increasing rear-end crashes. Tentative conclusions regarding traffic signals include the aforementioned and that signalized intersections having higher accidents but reduced severity and no real change in economic loss; no clear evidence exists that signal installation reduces crashes, especially where unwarranted; no clear justification for lowering warrants for rural signals exists, rather the opposite; and the right-angle crash rate is a better indicator than the number of right-angle crashes for assessment of the impact of signalization. In addition, as compared to two-phase signals, multiphase traffic signals at urban signalized intersections reduce fatal and injury crashes, manifested in a decrease in high severity left turn crashes offset by an increase in low severity rear-end crashes.

Ogden. Ogden, in a 1996 book devoted to the topic of safety, inserted a chapter devoted to intersections, which he asserts are the most critical element of the road network from a safety perspective (Ogden 1996). In this chapter, factors affecting safety at intersections are listed, including those in Table 2.5.

Table 2.5. Intersection safety factors

Number of legs	Turning radii
Angle of intersection	Lighting
Sight distance	Lane and shoulder widths
Alignment	Driveways
Auxiliary lanes	Right of way (rules, signs, and signals)
Channelization	Approach speed
Friction	

Addressing intersection control strategies, Ogden indicates that safety is one of the most important considerations in selecting a control strategy. Intersection control strategies, ordered by increasing degree of standard and control, include uncontrolled, relying on a priority rule to indicate right of way, priority road designated by GIVE WAY (YIELD) or STOP signs, roundabout, signal controlled, with turning traffic filtering through oncoming traffic, signal controlled, with control of some or all turning movements, or grade separations.

Using these control options, the design and operation of an intersection should allow, with minimum delay and maximum safety, vehicles and other road users to traverse the intersection or turn off the roadway. Finally, in contrast to indications by other sources, Ogden reports that intersections have a decreasing proportion of fatal crashes and that intersection crash severity is also falling.

American Association of State Highway and Transportation Officials. In 1997, the American Association of State Highway and Transportation Officials (AASHTO) published a guide for highway safety design and operations (AASHTO 1997). This publication covers many aspects of highway safety design and operations, including intersections. The role and responsibilities of safety management systems (SMS) are described as follows:

> "Identifying and investigating dangerous or potentially dangerous highway safety problems, roadway locations, and features (including railroad-highway grade crossings) and establishing countermeasures and priorities to correct the identified problems or potential problems."

> "Identifying the safety needs of special user groups (such as older drivers, pedestrians, bicyclists, motorcyclists, commercial motor carriers, and hazardous material carriers) in the planning, design, construction, and operation of the highway system."

The publication is divided by rural highway intersections and urban/suburban highway intersections. Rural intersections exist at major decision points along rural highways and, subsequently, are ranked as likely crash locations. According the National Safety Council (NSC), 32% of all rural crashes occur at intersections, with 16% of rural fatalities occurring in these crashes. Improvements at rural intersections that have shown to have positive impacts on crash history include the provision of left and right turn lanes, adequate sight distance, adequate design for safety and operational efficiency, and fixed lighting to reduce night-time crashes.

Related to urban/suburban intersections, the AASHTO report covers many categories, including those in Table 2.6. Channelization can increase driver understanding of wide or complex

Table 2.6. AASHTO urban/suburban intersection categories

Channelization	Accommodating elderly pedestrians
Sight distance	Refuge islands and medians
Turn lanes	Pedestrian barriers
Horizontal curves and super-elevation problems	Grade separations for pedestrians
Traffic diverters	Crosswalks
Left turn signal phasing	Audible pedestrian signals
Right-turn-on-red	Pavement surface

intersections, reducing crashes. Increased sight distance results in decreased crash rate and is a good countermeasure from a benefit/cost perspective. Exclusive left and right turn lanes can increase capacity, improve operation, and reduce rear-end crashes.

Kamyab and MacDonald. In 2000, Kamyab and MacDonald investigated the extent and impact of red light running in Iowa (Kamyab and MacDonald 2000). They note traffic signal violation-related crashes result in more than 800 deaths and thousands of injuries each year in the United States. Nationally, crashes involving motorists who disregard stop signs, yield signs, and traffic signals are 22% of urban crashes, causing roughly 7 billion dollars of economic loss. They also note a 24% in fatal crashes at intersections. They report 260,000 red light running crashes annually, resulting in 800 fatalities and 150,000 injuries, roughly 25% of fatalities and 30% of injuries nationally. They research a variety of driver behavior countermeasures, including automated enforcement, red light running programs, red light camera systems, and legislative responses.

Souleyrette et al. In 2001, Souleyrette, Kamyab, Knapp, and Hans reported on research related to identification of high crash locations (Souleyrette et al. 2001). In addition to other roadway characteristics, they considered intersections along rural four-lane expressways, identifying the top 30 Iowa high crash locations for this category. They identify a number of factors that influence rural intersection crash rates, including those in Table 2.7. Nothing is stated

Table 2.7. Factors influencing rural intersection crash rates

Time period	Shoulder and median width and type
Traffic volumes and movements	Lighting
Traffic control	Number of approaches
Geometry	Sight
Environment (e.g., urban or rural)	

about the effects these factors have on crash occurrence, however.

NCHRP reports. In 2001, TRB published an NCHRP report covering crashes at unsignalized intersections (TRB 2001a). This report is part of an effort to provide guidelines related to the AASHTO Strategic Highway Safety Plan (SHSP) effort to approach safety problems in a comprehensive manner, moving away from independent activities of engineers, law enforcement, educators, the judicial system, and other highway-safety disciplines and toward coordinated efforts. The AASHTO SHSP covers 22 goals impacting highway safety, including intersections. Of particular concern are unsignalized intersections, the predominant intersection type, because many have sufficient crash histories to indicate a need for improvement. Unsignalized intersections are sufficiently different than signalized intersections due to movement priorities on the main road. With an increasing demand for signalization of intersections in urban, suburban, and rural areas and considering that experience indicates a frequent increase in crash rates with signal installation, research into effective alternative intersection improvements is of active interest. Given this, objectives for improving safety at unsignalized intersections, other than signalization, include improved nearby access management, reduced frequency and severity of conflicts, improved sight distance, assisted driver gap size judgment, improved driver awareness of intersection along approaches, minimized crash frequency and severity through choice of appropriate selection of intersection traffic control, and reduced speeds on approaches.

Specific strategies for each of these objectives are identified in a table and detailed within the report. A replication of the table is shown in Table 2.8.

Table 2.8. Unsignalized intersection safety improvement objectives and strategies

Objective	Strategy
Improve management of access near unsignalized intersections	• Implement driveway closures/relocations • Implement driveway turn restrictions
Reduce the frequency and severity of intersection conflicts	• Provide left-turn lanes at intersections • Provide longer left-turn lanes at intersections • Provide offset left-turn lanes at intersections • Provide bypass lanes on shoulders at T-intersections • Provide left-turn acceleration lanes at divided highway intersections • Provide right-turn lanes at intersections • Provide longer right-turn lanes at intersections • Provide offset right-turn lanes at intersections • Provide right-turn acceleration lanes at intersections • Provide full-width paved shoulders in intersection areas • Restrict or eliminate turning maneuvers by signing • Restrict or eliminate turning maneuvers by providing channelization or closing median openings • Re-time adjacent signals to create gaps at stop-controlled intersections • Close or relocate "high risk" intersections • Convert four-legged intersections to two T-intersections • Convert offset T-intersections to four-legged intersections • Realign intersection approaches to reduce or eliminate intersection skew • Use indirect left-turn treatments to minimize conflicts between motorists and non-motorists
Improve sight distance at unsignalized intersections	• Clear sight triangles on stop- or yield-controlled approaches to intersections • Clear sight triangles in the medians of divided highways near intersections • Change horizontal and/or vertical alignment of approaches to provide more sight distance
Assist drivers in judging gap sizes at unsignalized intersections	• Provide an automated real-time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers • Provide roadside markers and pavement markings to assist drivers in judging the suitability of available gaps for making turning and crossing maneuvers

Table 2.8. (continued)

Objective	Strategy
Improve driver awareness of intersections as viewed from the intersection approach	• Improve visibility of intersections by providing enhanced signing and delineation • Improve visibility of the intersection by providing lighting • Install splitter islands on the minor-road approach to an intersection • Provide a stop bar (or provide a wider stop bar) on minor-road approaches • Install larger regulatory and warning signs at intersections • Call attention to the intersection by installing rumble strips on intersection approaches • Provide dashed marking (extended left edge lines) to define the median roadway area at divided highway intersections
Choose appropriate intersection traffic control to minimize crash frequency and severity	• Avoid signalizing through roads • Provide all-way stop control at appropriate intersections • Provide roundabouts at appropriate locations • Install flashing beacons at stop-controlled intersections
Improve driver compliance with traffic control devices and traffic laws at intersections	• Provide targeted enforcement to reduce stop-sign violations • Provide automated enforcement of stop-sign violations • Provide targeted public information and education on safety problems at specific intersections
Reduce speeds on specific intersection approaches	• Provide targeted speed enforcement • Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices

In 2002, TRB published an NCHRP report covering crashes at signalized intersections (TRB 2002b). This report provides guidelines to promote a comprehensive approach to safety problems. Specific strategies for each of the signalized intersection objectives are identified in a table and detailed within the report. A replication of the table is shown in Table 2.9.

Table 2.9. Signalized intersection safety improvement objectives and strategies

Objective	Strategy
Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	• Employ multiphase signal operation • Increase clearance intervals • Restrict or eliminate turning maneuvers (including right turns on red) • Employ signal coordination and preemption • Remove unwarranted traffic signals • Improve intersection traffic control of pedestrian and bicycle facilities
Reduce frequency and severity of intersection conflicts through geometric improvements	• Provide/improve left-turn lane channelization • Provide/improve right-turn lane channelization • Improve geometry of pedestrian and bicycle facilities • Revise geometry of complex intersections • Construct special solutions
Improve sight distance at signalized intersections	• Clear sight triangles at intersections • Redesign approaches
Improve driver awareness of intersections and signal control	• Improve visibility of intersections • Improve visibility of signals and signs at intersections
Improve driver compliance with traffic control devices	• Provide targeted enforcement • Provide red-light running cameras • Provide speed enforcement cameras • Provide public information and education • Provide traffic calming on intersection approaches

Table 2.9. (continued)

Objective	Strategy
Improve access management near signalized intersections	• Restrict access to properties, using driveway closures or turn restrictions • Restrict cross median access near intersections
Other improvements	• Improve drainage in intersection and on approaches • Provide skid resistance in intersection and on approaches • Coordinate closely-spaced signals near at-grade railroad crossings • Relocate signal hardware out of clear zone • Restrict or eliminate parking on intersection approaches

Thomas. In 2001, Thomas studied the effectiveness of roadway safety improvements in Iowa (Thomas 2001). Thomas reviewed 94 Iowa traffic safety projects to determine crash reduction factors and benefit/cost ratios for seven different improvement categories. The overall analysis shows that Hazard Elimination System (HES) and Transportation Safety Fund (TSF) projects had a mean crash reduction of 23%, with the HES projects having an average of 40% reduction and the TSF projects having an average of 21% reduction. An overall mean B/C ratio of 6.3 is determined, again with HES projects having a mean B/C ratio of 2.6 and TSF projects having a mean B/C ratio of 6.9. The analysis shows that adding turn lanes while modifying the signal phasing had a crash reduction of 58%. Replacing pedestal-mounted signals with mast-arm mounted signals reduced crashes by 36%. Adding turn lanes without signal improvements only reduced crashes by 12%. Other project categories examined include installation of new signals, adding turn lane(s), adding new signal and turn lane(s), add left-turn phasing, and other geometric improvements, but none of these showed significant results. The study notes the phenomenon of regression-to-mean and suggests methods that might account for it.

Intersection safety analyses

Many analyses related to intersection safety have been performed. Some sought to increase knowledge for improved intersection design and operation. Others proposed methods for visually detecting safety deficiencies at intersections. Still others assessed the potential for analyzing intersection characteristics to determine potential safety problems. Three main ideas are clear: intersection safety has been of interest for several decades; many analyses have been repeated; and overall knowledge of intersection safety remains unclear.

Iowa State Highway Commission. In 1962, the Iowa State Highway Commission published a report on the effects of channelization for at-grade highway intersections (Iowa State Highway Commission 1962). The commission sought to "promulgate the idea of channelization." It determined that channelization reduces the area of conflict, provides refuge for turning and crossing vehicles, separates conflict points, blocks prohibited turns, provides installation locations for traffic control devices, and is required for effective signal control at complex intersections.

Perkins and Harris. In 1967, Perkins and Harris proposed a traffic conflict technique for assessing the safety performance of individual intersections (Perkins and Harris 1967). They define a traffic conflict as any potential accident situation and propose 20 objective criteria that indicate specific accident patterns. These criteria are defined by occurrence of evasive actions, such as braking and weaving. The authors claim that observation of the traffic at intersections provides insight into causal factors and propose a method for observing intersections that involves three 12-hour sessions at each intersection.

Box and Associates. In 1970, Box and Associates reviewed the relationship of various traffic control and roadway elements to highway safety (Box and Associates 1970). They note that reporting agencies have differing definitions of intersection-related crashes. They indicate that arbitrary definitions have severe limitations and may obscure the effect of intersection characteristics on traffic crashes. They also describe that several studies have found different effects of roadway elements. Factors that may account for this include inaccurate crash classification, incomplete files, or use of statistically insignificant time periods or crash frequencies. Related to this last factor, the authors define the statistical phenomenon of "regression to the mean" and the importance of neutralizing the effect. Finally, they indicate that intersection geometric layout and traffic controls are related to crash rates. The geometric layouts analyzed include L-, Y-, T-, offset, and cross intersections. The traffic controls analyzed include yield, two-way stop, four-way stop, and traffic signals.

Glennon et al. In 1977, Glennon, Glauz, Sharp, and Thorson reported on their review of the traffic conflicts technique proposed by Perkins and Harris in 1967 (Glennon et al. 1977a, 1977b). They begin by questioning the reliability of the traffic conflict technique and its association to actual crash occurrence. In their review, they mention various applications and reviews of the technique over the past decade. One evaluation found that conflicts and crashes are associated and that the technique may be used to identify potential problems more quickly. However, Glennon et al. identify several deficiencies with the evaluation. Similar conclusions resulted from the other studies evaluated. In conclusion, Glennon et al. question the reliability of the technique.

McGee. In 1978, McGee evaluated the effectiveness of the recently enacted right-turn-on-red rule (McGee 1978). Right-turn-on-red crashes were "very infrequent compared with all intersection accidents," and the policy "does not significantly degrade the safety." With the decrease in delay, right turn on red was determined to be a good policy.

Williams. In 1978, Williams evaluated driver behavior during the yellow interval of a signal phase (Williams 1978). The evaluation had a threefold purpose: to determine driver characteristics, to determine stopping ability, and to present a method for determining length of urban intersection clearance interval.

Basu. In 1979, Basu prepared a report for the Iowa Highway Research Board (HRB) that evaluated the effectiveness of intersection stop rumble strips (Basu 1979). The intent of rumble strips is to alert drivers through aural and tactile stimuli and cause them to slow down or stop. The report was inconclusive.

Radwan and Sinha. In 1980, Kumares and Sinha evaluated potential countermeasures for improving safety at multilane rural intersections (Kumares and Sinha 1980). Their objective was "to apply a computer model to evaluate design and control alternatives" to improve safety at multilane rural intersections. They conducted field studies for gap acceptance, traffic delay, and traffic conflicts. These results were used to assess model validity.

Glauz and Mitletz. In 1980, Glauz and Mitletz published another assessment of the traffic conflicts technique (Glauz and Mitletz 1980a, 1980b). They indicate that strong correlations between conflicts and accidents have been difficult to determine or trust. They contend that identified operational traffic conflicts must not only imply a safety-related attribute but must also satisfy other attributes, including safety-relatedness, site-relatedness, reliability, repeatability, and practicality. They identify 14 different basic intersection conflicts from this. They note that the method is time-consuming and should not be used indiscriminately but rather when a site has been tagged as hazardous by some other method or for confirming operational deficiencies indicated by crash history.

Insurance Institute for Highway Safety. In 1980, the Insurance Institute for Highway Safety (IIHS) published a report opposing right-turn-on-red laws (Insurance Institute for Highway Safety 1980). Citing increases in right-turn-related crashes and pedestrian-related crashes, they argue for repeal of the laws. Two related articles came out reiterating and supporting the conclusions of IIHS (Chicago Tribune 1981; Journal of American Insurance 1981).

Zegeer et al. In 1982, Zegeer, Opiela, and Cynecki evaluated the effect of pedestrian signals and timing on pedestrian accidents (Zegeer et al. 1982). Data related to pedestrian accidents, intersection geometrics, traffic and pedestrian volumes, roadway environment, and signal operation were collected for 1297 intersections in 15 cities. Using various statistical techniques, the authors found no significant difference between intersections with standard-timed pedestrian signals and intersections without any pedestrian signalization. They also determined that exclusive-timed locations experienced reduced accident experience for intersections with moderate-to-high pedestrian volumes.

Clark et al. In 1983, Clark, Maghsoodloo, and Brown evaluated the effects of right-turn-on-red laws on highway safety, fuel consumption, and air pollution in South Carolina and Alabama (Clark et al. 1983). They determined that several benefits resulted, including fuel savings, reduced vehicle emissions, and reduced delay.

Zador et al. In 1985, Zador, Stein, Shapiro, and Tarnoff examined the effect of signal timing on traffic flow and crashes at signalized intersections (Zador et al. 1985). Using data from 91 signalized intersections throughout the United States, they determined that intersections with "more adequate clearance intervals" had lower frequencies of rear-end and right-angle crashes.

Zegeer and Cynecki. In 1986, Zegeer and Cynecki evaluated countermeasures related to right-turn-on-red pedestrian crashes (Zegeer and Cynecki 1986). Their purpose was to field test the most promising right-turn-on-red pedestrian accident countermeasures. They tested signing options, signal modifications, pavement markings, design changes, and other treatments (e.g., intersection lighting and removal of roadside clutter).

Mahalel and Prashker. In 1987, Mahalel and Prashker presented a "conceptualized approach" for estimating the risk of signalized intersection rear-end collisions (Mahalel and Prashker 1987). Using data from four intersections, they concluded that a long warning period causes a significant increase in the number of rear-end collisions.

Hauer et al. In 1988, Hauer, Ng, and Lovell presented the results of a study that confirmed the appropriateness of using traffic flows related to the conflicts being investigated (Hauer et al 1988). Using a data set of 145 four-legged, fixed-time, signalized intersections in Toronto, they conclude that vehicle maneuver has a better relationship to traffic flow than initial impact type. They propose 15 accident patterns and intersections and suggest that comparing the accident history of the patterns to what should be expected is an appropriate measure of safety. To estimate the expectation, they suggest an assessment of variability in the crash history of similar intersections.

Lau and May. In 1988, Lau and May propose injury accident models for signalized intersections (Lau and May 1988). They use classification and regression trees (CART) to build the injury accident models. The factors found to be significant include traffic intensity, proportion of cross street traffic, intersection type, signal type, number of lanes, and left turn arrangements.

Persaud. In 1988, Persaud presents some methodological issues with past evaluations of traffic signal safety (Persaud 1988). He identifies two common pitfalls, regression to the mean, and incorrect inferences from cross-section studies. He contends that there is "very little substantial knowledge" about traffic signal safety impact and proposes that empirical Bayesian (EB) methods can be used to improve the status of knowledge.

Agent. In 1988, Agent attempted to determine the types of rural high-speed intersection traffic control, establish the type of accidents that occur at these intersections, discover contributing factors, and recommend traffic control measures to decrease accident potential (Agent 1988). He examines site characteristics, traffic controls, and accidents at 65 mph, rural, high-speed intersections. He concludes that adequate driver warning is of primary importance and that providing a proper change interval and maximizing signal head visibility are beneficial.

Parker and Zegeer. In 1989, Parker and Zegeer revisited the topic of traffic conflict techniques, preparing a guide for engineers (Parker and Zegeer 1989a, 1989b). They note numerous problems and limitations of only using accident reports for safety analysis and highlight benefits and advantages to conducting traffic conflict studies. They note that traffic conflict studies are an excellent tool for studying locations singled out for review by some other method. They indicate the proper application of traffic conflict studies and suggest when these studies ought be conducted.

NCHRP 320. In 1989, TRB published guidelines for converting stop control to yield control at intersections (TRB 1989). Using a literature search, a survey of state and local traffic engineers, and analysis of 765 intersections, they developed a series of guidelines to assist engineers in assessing possible conversions. They note that prior research had indicated potentially large reductions in fuel consumption, vehicle operating costs, motorist delay, and vehicle emissions if intersections were converted.

Upchurch. In 1991, Upchurch investigated the effect of five types of left turn phasing: permissive, leading exclusive/permissive, lagging exclusive/permissive, leading exclusive, and lagging exclusive (Upchurch 1991). Using "simple comparison design" and "a simple before-and-after design," various observations and conclusions are made:

- Leading exclusive phasing has the lowest left-turn accident rate.
- With two opposing lanes:
    - lagging exclusive/permissive has the worst accident rate;
    - the order of safety (from best to worst) is leading exclusive, permissive, leading exclusive/permissive, and lagging exclusive/permissive.
- With three opposing lanes:
    - leading exclusive/permissive has the worst accident rate;

  - the order of safety (from best to worst) is leading exclusive, lagging exclusive/permissive, permissive, and leading exclusive/permissive.
- In three out of four cases, accident rates are higher with three opposing lanes.

Garber and Srinivasan. In 1991, Garber and Srinivasan looked at intersection accidents involving elderly drivers (Garber and Srinivasan 1991a). They cite statistics indicating that elderly drivers are increasingly involved in intersection crashes. They identify intersection traffic and geometric characteristics associated with elderly driver crash involvement. They find that rural involvement risk is higher for elderly drivers. In addition, they find that elderly drivers involved in intersection crashes are more likely than younger drivers to have committed some traffic violation prior to the crash.

Garber and Srinivasan. In 1991, Garber and Srinivasan presented the statistical modeling methods used in assessment of risk for elderly drivers at intersections (Garber and Srinivasan 1991b). Specific objectives of the research presented included the following: identification of a suitable method of expressing elderly driver involvement risk, determination of mathematical relationships between elderly driver risk and significant traffic and geometric characteristics, and identification of changes in design and operation parameters to enhance elderly driver safety. Linear and logit models were developed for cross-signalized intersections.

Parker. In 1991, Parker published a report that detailed methods for development of expected values for accident analysis at intersections (Parker 1991). He notes that safety investigators have known for a long time that accident data alone provide only a limited view of intersection safety. He notes problems and limitations with relying solely on accident reports. He identifies two methods for identifying abnormal accident patterns: cluster analysis and expected value analysis. After briefly describing each, he clarifies that cluster analysis requires subjective evaluations. However, expected value analysis is a "scientifically-based method for identifying abnormal accident patterns." He mentions the use of statistical tests based on Poisson, gamma, or negative binomial distributions. Expected values for use in these tests are developed from accident data from sites, with site expectancies identified from averages at like sites.

Bonneson and McCoy. In 1993, Bonneson and McCoy investigated the safety at rural stop-controlled intersections (Bonneson and McCoy 1993). Using a generalized linear modeling approach, they developed a model relating unsignalized intersection traffic demands to accident frequency. Their results support the idea that the negative binomial distribution may be used to describe the distribution of accident counts and that the gamma distribution may be used to describe the mean accident frequency at similar intersections. Using expected number of accidents per year to define safety, they develop a methodology for assessing safety and efficiency. In their model, time period and traffic demand represent exposure. Accident probability was affected by urban/rural environment, traffic control, access point frequency, speed limit, shoulder width, median type, median width, lighting level, left-turn bay availability, number of legs, and number of traffic lanes. They identify issues with sample size and intersection similarity. Their resultant model is a generalized linear model.

Huang and Pant. In 1994, Huang and Pant evaluated dilemma zone problems at high-speed signalized intersections using simulated neural network models (Huang and Pant 1994). The effectiveness of traffic control devices at these types of intersections is sensitive to roadway geometric, speed distribution, and traffic volume. A model was developed to represent these devices and assess the safety of these intersections without accident history.

Maze et al. In 1994, Maze, Henderson, and Sankar examined the impacts of left-turn treatments at high-speed signalized intersections (Maze et al 1994). They cite figures that suggest that left turning traffic is over-represented in crash involvement. Their objectives were to develop models estimating approach accident rates and to quantify the relationship between traffic and intersection characteristics. This latter objective was focused on the accident potential of left turn treatments. Using regression models, they modeled the ratio of the number of left turn accidents to left turning vehicle per approach and the ratio of accidents to traffic movements per approach. Results indicate that protected left turn phasing is safer, left turn lanes and multiple lanes reduce accident rates, raised medians increase accident likelihood, and signals included in a signal system have lower rates than isolated signals.

Retting and Williams. In 1996, Retting and Williams investigated the characteristics of red light violators using field investigations (Retting and Williams 1996). Using automated cameras, trained observers, and driver records, they developed a profile of red light runners at an urban intersection. They found that red light runners tended to be younger, were less likely to wear seat belts, had poorer driving records, and drove smaller, older vehicles. They note that removal of traffic signals might be an alternative to solve this problem.

FHWA. In 1996, the Federal Highway Administration published a report explaining various statistical models for at-grade intersection accidents (FHWA 1996). The alternative modeling approaches investigated include Poisson, lognormal, negative binomial, and logistic distributions. The model development results in statistical models for five types of intersections: rural and urban three- and four- legged stop-controlled intersections and urban four-legged signalized intersections.

They note that past efforts using multiple linear regression have had disappointing results and list several reasons for this. They suggest use of the Poisson distribution as an initial step, with application of the negative binomial where appropriate.

Long and Gan. In 1997, Long and Gan developed a model for minimum driveway corner clearances at signalized intersections (Long and Gan 1997). They note that traffic dissipation is more important under saturated flow conditions and safety is the major concern during undersaturated conditions. They note that corner clearances are different under each condition and that corner clearances should be set to best suit both flow conditions. They suggest that their model is more flexible than the existing tabular guidelines.

Persaud et al. In 1997, Persaud, Hauer, Retting, Vallurupalli, and Mucsi investigated the effects of traffic signal removal in Philadelphia (Persaud et al. 1997). Using crash and traffic control data from one-way street intersections where signal control was converted to multiway stop sign control, they used an empirical Bayesian procedure to estimate crash history had the intersections not been converted. Aggregate results indicate that the conversion resulted in a 24% reduction.

Pietrzyk and Weerasuriya. In 1997, Pietrzyk and Weerasuriya examined four-legged intersections in order to develop expected value conflict tables (Pietrzyk and Weerasuriya 1997). They note that expected value analysis was widely used to estimate type and frequency of intersection crashes but that current analysis is based on a 1982 FHWA study. The conflict tables are then used to estimate over-representation of certain crash types and identify intersections with safety and operational problems.

Staplin et al. In 1997, Staplin, Harkey, Lococo, and Tarawneh released the results of an FHWA study focused on geometric design and operational guidelines for older drivers and pedestrians at intersections (Staplin et al. 1997). They determined the geometric and operational changes most likely to aid older drivers and pedestrians. Both of these groups are significantly impacted by crashes at intersections.

Lee and Berg. In 1998, Lee and Berg developed safety-based level-of-service (LOS) parameters for two-way stop-controlled intersections (Lee and Berg 1998). They note that current LOS evaluative methods do not account for safety. They focused on sight distance improvements because these types of improvements are the "most cost-effective" of the various safety enhancements at intersections.

Persaud and Nguyen. In 1998, Persaud and Nguyen investigated use of the empirical Bayesian approach for three- and four-legged intersection analysis (Persaud and Nguyen 1998). They produced aggregate and disaggregate models to related safety performance to intersection characteristics. The resultant models, or safety performance functions, can be the basis for examining the safety effect of alternate design options and development of safety warrants. The SPFs can also be used in an EB framework to estimate individual intersection safety. Tasks identified as part of safety evaluation include hazardous location identification, diagnosis of safety problems, safety treatment prioritization, and evaluation. The authors claim that modern techniques demand use of SPFs. The only independent variable was traffic flow, with other characteristics included as part of separate groups with separate models.

Weerasuriya and Pietrzyk. In 1998, Weerasuriya and Pietrzyk developed expected conflict value tables for three-legged intersections (Weerasuriya and Pietrzyk 1998). They note the high percentage of intersection crashes as justification for their efforts. Using their tables, if an intersection exhibits greater than expected conflict rates, improvement of the intersection can be justified, developed, implemented, and later evaluated.

Vogt and Bared. In 1998, Vogt and Bared developed accident models for rural two-lane segments and intersections (Vogt and Bared 1998). They assert that safety and economy are primary engineering goals and should also be an important aspect of planning and design. They also note that intersection models are rare and less promising for relating design elements to accidents. Using an analysis representing the mean by a product of highway variables to various powers, they developed a model they called an extended negative binomial model. They also developed accident reduction factors but note that these factors must be used with care. They note that the factors depend on the presence of all interacting variables and could change substantially if the variables were replaced or omitted. Finally, they note a possible empirical Bayesian extension.

Rodriguez and Sayed. In 1999, Rodriguez and Sayed developed accident prediction models for urban signalized intersections (Rodriguez and Sayed 1999). Using a generalized linear modeling approach to address and overcome shortcomings of conventional linear regression, they refined their model using the empirical Bayesian approach. Four applications of the models are discussed: identification of accident prone locations, development of critical accident frequency curves, ranking, and before-and-after evaluation. They note that limited budgets and growing fiscal constraints demand more efficient utilization of resources.

Sebastion. In 1999, Sebastion analyzed collisions due to left turn maneuvers at signalized intersections (Sebastian 1999). She notes that left turn maneuvers have significant operational and safety impacts. Addition of left turn phasing may improve safety but also increases delay. She found no significant differences in left turn opposing crash rate for various geometric configurations.

Phasing operation had the greatest impact, with protected/permissive phasing most likely to have high crash rates.

Lu and Brett. In 1999, Lu and Brett developed a procedure to prioritize intersections for safety improvements (Lu and Brett 1999). They note that a roadway intersection must be analyzed in terms of safety, geometric, and operational considerations and developed separate lists for each of these. They then analyzed various combinations of these lists and conclude that prioritization based on both safety and operational factors will better reflect needed intersection improvements.

Retting et al. In 1999, Retting, Ulmer, and Williams revisited the topic of red light running crashes (Retting et al. 1999). They note that 40% of crashes occur at intersections and that crash frequency at signalized intersections has increased considerably, primarily due to driver disregard for traffic signals. They studied red light running crashes to identify characteristics of crashes and the drivers involved. They found that red light violators tended to be young and male, with driving while intoxicated violations, invalid drivers licenses, and alcohol in their system.

HSIS. In 2000, a Highway Safety Information System (HSIS) report related to red light running crashes was published (HSIS 2000). The report notes the recent prevalence of red light running crashes, citing that 16% to 20% of total intersection crashes are related to red light running. The purpose of the study was to examine intersection geometric characteristics and their relationship to red light running crash rates. Increase in red light running crashes seems related to higher average daily traffic on cross streets.

NCHRP 457. In 2002, TRB published an engineering study guide for intersection improvement evaluation (TRB 2002a). The guide provides steps and details related to assessing improvements to intersections, suggesting that some common thoughts might need to be rethought. The intersection improvements covered include add flash mode to signal control, convert to traffic signal control, convert to multi-way stop control, convert to two-way stop control, convert to two-way yield control, prohibit on-street parking, prohibit left turn movements, convert to roundabout, add a second lane on the minor road, add a left turn bay on the major road, add a right turn bay on the major road, increase the length of the turn bay, and increase right turn radius. Details regarding each alternative are included in the guide.

Iowa SMS. In 2002, the Iowa Safety Management System published a toolbox of safety strategies related to several topics, including intersections (SMS 2002a, 2002b). The stated goals are as follows:

- Reduce the crash rate and the severity of crashes occurring at Iowa intersections.

- Increase consideration for older drivers and pedestrians in the design of intersection improvements.
- Increase funding for the Iowa Traffic Safety Fund (TSF) program.
- Provide additional traffic safety training for state, county, and city engineering staff.

The toolbox notes that intersections "constitute a very small part" of highway systems but are involved in a "notable portion" of crashes. The publication lists several potential safety strategies that might be implemented by multiple disciplines, including legislation, policy, and enforcement; education and public awareness; design and technology; and access management. Finally, several successes and implemented strategies are discussed.

HSIS. In 2002, another HSIS report related to intersections was published (HSIS 2002). The research was related to safety effectiveness of intersection left and right turn lanes. Within the report, the point is made that many of the past estimates of safety effectiveness are questionable because past studies were poorly designed and executed. Using 580 intersections, the researchers evaluated 280 improvement projects related to left and right turn lanes. The evaluation was carried out using three different before-and-after approaches: yoked comparisons, comparison group, and the empirical Bayes approach. The conclusion was that, due to regression to the mean, the best evaluation approach is the EB approach. The authors claim that EB is the "only known technique to account for the effect of regression to the mean on evaluation results."

Harwood et al. In 2002, Harwood, Bauer, Potts, Torbic, Richard, Kohlman Rabbani, Hauer, and Elefteriadou published a draft report on the safety effectiveness of intersection left and right turn lanes (Harwood et al. 2002). The research evaluated 280 intersections that were improved but had 300 more intersections for reference or comparison. The report covered a wide range of intersection geometric, traffic control, and operation features, as well as traffic characteristics, in the literature review. The authors assert that "by the quantity of the studies related to left and right turn lanes that there is considerable interest in quantifying their safety effectiveness." Using three different before-after evaluation approaches, they assess the best method for evaluation. They conclude that the EB approach is the best method and cite the following three features:

- EB accounts for selection bias, whereas the yoked-comparison (YC) and comparison group (CG) approaches do not.
- EB accounts for changes (e.g., volume increases) from the "before" to "after" period explicitly.

- EB can use many years of data, while the others cannot.

The authors note the advantages of EB but also caution that it requires more complete data and greater analysis effort. They also assert that "the EB approach is the only evaluation approach with the potential to compensate for regression to the mean." Finally, they conclude with statements regarding the effectiveness of left and right turn lanes and provide guidance regarding choice of evaluation approaches.

FHWA. In 2002, the FHWA published a series of intersection briefing sheets (Federal Highway Administration 2002). These briefing sheets introduce the national intersection safety problem and some basic countermeasures to make intersections safer. A series of brief reports related to specific aspects of intersection safety are presented, including the topics of pedestrians, human factors, enforcement, traffic control devices, red light running, red light cameras, and work zones. The sheets conclude with a presentation of some commonly believed intersection safety myths and provide information related to additional resources. All of the sheets are written in an easily understandable manner.

CHAPTER 3. BAYESIAN THEORY

In this chapter, a brief synopsis of Bayesian philosophy is presented before proceeding into detail about Bayesian theory. One method of estimating a Bayesian model result (i.e., Gibbs sampling) is discussed, along with a discussion of generalized linear models (GLIMs), which form the basis of the model. The discussion of Bayesian theory continues with a discussion of potential challenges to the implementation of Bayes' Theorem, and concludes with comments on its inherent advantages.

Bayesian Philosophy

The term "Bayesian data analysis" is meant to indicate "practical methods for making inferences from data using probability models" about observed quantities of interest (Gelman et al. 1998). Probability is fundamentally the measure of risk or uncertainty. Bayesian methods are used to make statements about some unknown quantity in a systematic way using the partial knowledge (data) available. Probability is used to describe the state of knowledge of the unknown.

One primary motivation for using Bayesian thought is that common-sense interpretation of statistical conclusions is facilitated (Gelman et al. 1998) . For example, a Bayesian interval (a probability interval or credible set) for some unknown quantity of interest is directly interpreted to have a high probability of containing the quantity. This contrasts with the frequentist interval (the confidence interval), which may only be strictly interpreted with relation to a series (from repeated practice) of similar inferences. That is, the frequentist α% confidence interval (CI) is interpreted as follows: If we were to repeat the experiment many times, α% of the CI would cover the true parameter value.

Using Bayesian statistics, it is natural to consider the probability of an unknown lying in a particular range of values (Gelman et al. 1998) . It is equally natural to consider the probability that the mean of a random sample from a fixed population falls within a defined range. The former allows statements about data that have already been collected; the latter facilitates statements about future occurrences.

Statistical inference is the attempt to draw conclusions from data, $\mathbf{y}$, about unobserved quantities or parameters, θ, denoted by the analyst (that are expressed in words and thoughts) (Gelman et al. 1998). At the basic level of conditioning on the data, Bayesian inference departs from standard statistical inference. Standard inference is based on a retrospective evaluation of the procedure used to estimate the unobservable vector quantities or population parameters of interest, θ, (e.g., the probabilities of a crash given certain intersection characteristics) over the distribution of possible observed data, y, (e.g., intersection crash frequencies) conditional on the true unknown value of θ. Bayesian statistical conclusions are made in terms of probability statements, conditional on the observed value of y. Bayesians condition on the known values of covariates implicitly. Despite this difference, it is possible in many simple analyses to reach similar conclusions using the two different inferential methods, standard and Bayesian. The Bayesian framework, due to its flexibility and generality, lends itself to analysis of very complex problems. In fact, many Bayesian properties are attractive to frequentists (Carlin and Louis 2000).

Two opposing arguments, both subjective in that they require judgments about the nature of tested quantity and the procedure to test it and both involving semantic arguments regarding the definitions of "equally likely events," "identical measurements," and "independence," have been put forth and signal a contrast between Bayesian and frequentist thought (Gelman et al. 1998). The first, a Bayesian argument, is the symmetry or exchangeability argument. It states:

probability = the number of favorable cases/the number of possibilities,

assuming equally likely possibilities. The second, the frequentist argument, states:

probability = the relative frequency obtained in a very long sequence of samples,

assumed to be performed in an identical manner, physically independent of each other. The latter, the frequency argument, has the perception of difficulties arising from its hypothetical requirement of a very long sequence of identically obtained samples. Taken strictly, a frequency viewpoint does not allow for a probability statement concerning a single sample not embedded, at least conceptually, in a long sequence of identical events (Gelman et al. 1998). This is a partial source of the difficulties in using frequentist methods to describe the results of random, rare events such as traffic crashes.

An additional argument for using the Bayesian paradigm instead of frequentist methods is that all probabilistic statistical methods are subjective in that they rely on mathematical idealizations of a quantity (Gelman et al. 1998). Though Bayesian methods are sometimes regarded as "subjective" due to reliance on prior distribution(s), in fact, most problems rely on some type of scientific judgment to specify the "likelihood" and prior parts of a model. Prior information used in analyses might range from knowing that a crash has happened or not (e.g., $p(\theta = \text{crash}) = p(\theta = \text{no crash}) = ½$) to the proper distribution to fit random, rare, count events (e.g., Poisson or negative binomial). For example, linear regression models often assume prior distributions about the regression parameters, without any mechanism for adjustment. Whenever another analysis occurs or additional data are obtained, the Bayesian-based database and knowledge grow. This facilitates estimation of a probability distribution from these data, which results in a more "objective" analysis. If replication occurs many times, the prior distribution parameters can eventually be estimated from the data. In the end, scientific judgment will still be required to define certain elements, notably the choice of data to be included in the analysis, the parametric forms of the distributions, and the ways in which the model is checked. However, this is no more than what frequentist methods would require.

In summary, the Bayesian inference process involves transitioning from a prior distribution, $p(\theta)$, to a posterior distribution, $p(\theta|y)$. One might naturally expect that some general relations would hold through the transition (Gelman et al. 1998). It might be expected, for example, that because the posterior distribution incorporates the information from the data, it will be less variable than the prior distribution.

Once the posterior distribution has been defined there is a great degree of flexibility with which posterior inferences can be summarized, even after complicated model transformations (e.g., log, power) (Gelman et al. 1998). This is a key advantage of the Bayesian approach. Bayesian analysis also provides corollaries to common frequentist numerical summary data: means, medians, modes, standard deviations, and quantiles. The Bayesian mean is the posterior parameter expectation and the Bayesian mode is the value with the highest probability of occurrence, both given the data and the model.

Bayesian Theory

Bayesian data analysis relies on Bayes' Theorem, a fundamental theorem for "inverting" probabilities. Bayes' Theorem states that

$$\begin{aligned} p(\theta|y,\eta) &= p(y,\theta|\eta) \,/\, p(y|\eta) \\ &= p(y,\theta|\eta) \,/\, \int p(y, \mathbf{u}|\eta)\, d\mathbf{u} \qquad (1) \\ &= f(y|\theta)\, \pi(\theta|\eta) \,/\, \int f(y|\mathbf{u})\, \pi(\mathbf{u}|\eta)\, d\mathbf{u}. \end{aligned}$$

As shown in the equation, following the Bayesian approach involves the specification of a model for the observed data $\mathbf{y} = (y_1, \ldots, y_n)$ given a vector of unknown parameters $\boldsymbol{\theta} = (\theta_1, \ldots, \theta_K)$, usually in the form of a probability distribution $f(y|\theta)$ (i.e., the likelihood) (Carlin and Louis 2000). In addition, we assume $\boldsymbol{\theta}$ is a random quantity, having a prior distribution $\pi(\theta|\eta)$, where $\boldsymbol{\eta}$ is a vector of hyperparameters. Hyperparameters are additional parameters, in additional levels of the model, which define the uncertainty about the individual parameters of the previous model level. These hyperparameters reflect the Bayesian philosophy of treating all variables as random. Inference concerning $\boldsymbol{\theta}$ is then based on its posterior distribution, $p(\theta|y,\eta)$, given by Bayes' Theorem.

The contribution of both the experimental data (in the form of the likelihood f) and prior opinion or knowledge (in the form of the prior π) to the posterior is evident in the last expression of the equation (Carlin and Louis 2000). The denominator is sometimes written as $m(y|\eta)$, which is the marginal distribution of the data y given the value of the hyperparameter η. If η is known, often it is suppressed in the notation, since it would be a constant. In this case, Bayes' Theorem would result in the posterior distribution, $p(\theta|y)$. This, as will be shown, is not the case in the model developed as part of this dissertation.

If unsure of the proper value for η, Bayesians would quantify the uncertainty in a second-stage prior distribution (a hyperprior) (Carlin and Louis 2000). Denoting the second-stage prior distribution by $h(\eta)$, the posterior for $\boldsymbol{\theta}$ is obtained by marginalizing (i.e., analyzing the model via the marginal distributions) over η also:

$$\begin{aligned} p(\theta|y) &= p(y,\theta) / p(y) \\ &= \int p(y,\theta,\eta)\, d\eta \,/ \iint p(y, \mathbf{u},\eta)\, d\eta\, d\mathbf{u} \qquad (2) \\ &= \int f(y|\theta)\, \pi(\theta|\eta)\, h(\eta)\, d\eta \,/ \iint f(y|\mathbf{u})\, \pi(\mathbf{u}|\eta)\, h(\eta)\, d\eta\, d\mathbf{u}. \end{aligned}$$

Alternatively, using a method referred to as empirical Bayes (EB) analysis, η could be replaced by an estimate $\hat{\eta}$. EB reduces the problem of marginalizing over η to a problem of estimating $\hat{\eta}$ and, rather than using distributions, using point estimates (Carlin and Louis 2000).

Empirical Bayes uses data to estimate the prior parameter η. The approach uses both the likelihood form and the observed data for determination of the prior, referred to as empirical estimation of the prior (Carlin and Louis 2000). Due to the use of the data twice (in the prior and in the likelihood), empirical estimation of the prior violates the Bayesian philosophy and is not often used within statistics. The effect of this double use of the data is that the resulting inferences from the posterior are "overconfident". EB methods that do not account for this are referred to as "naïve". Despite this, and due to much effort to correct the "overconfident" inferences, EB methods are still used. Advances in computing and computational methods now allow for consideration of more complex integration, making hierarchical Bayesian analysis more feasible.

Both "straight" or "pure" Bayesian and "empirical" Bayesian analyses can be further extended by hierarchical modeling, often referred to as "hierarchical Bayes" (Carlin and Louis 2000). Most often, however, hierarchical Bayes refers to the extension of "pure" Bayes and not EB.

Hierarchical Bayesian statistics refers to the specification of a Bayesian model over several levels, with each new distribution forming a new level in the hierarchy (Carlin and Louis 2000). From the previous discussion, the hyperprior η would depend on a collection of unknown parameters λ, resulting in a generalized hyperprior equation with a second-stage prior $h(\eta|\lambda)$ and a third-stage prior $g(\lambda)$. The problem defines the proper number of levels, though with increasing levels comes less knowledge about those levels, decreasing the benefit of the additional level. As the number of levels increase, randomness is increased, which means that changes at the top are not likely to affect the bottom level (the data level), that for which observations exist. The simplest model has only two levels (likelihood and prior).

Equation (2) may be expressed in convenient shorthand denoting that "the posterior is proportional to the likelihood times the prior" (Carlin and Louis 2000):

$$p(\theta|y) \sim f(y|\theta)\, \pi(\theta).$$

Bayes' Theorem may be used sequentially when a full data set $(\mathbf{y_1},\mathbf{y_2})$ is collected in two stages by first finding $p(\theta|y_1)$ and then using $p(\theta|y_1)$ as the prior for the second set of data, y_2. This has some implications:

1. The first portion, $\mathbf{y_1}$, can be used to "calibrate" the model that can then be "validated" by the second portion, $\mathbf{y_2}$.
2. The results from a previous analysis can be used as part of the prior knowledge for a subsequent analysis.

The Bayesian data analysis process can be idealized into a few, well-defined steps (Gelman et al. 1998):

1. Development of the full probability model. This full probability model is a joint probability distribution that includes all quantities in a problem, both observable and unobservable. The model should remain consistent with knowledge about the problem and the process of data collection.

2. Conditioning on the observed data. This involves calculation and interpretation of the appropriate posterior distribution, the posterior distribution being the conditional probability distribution of the unobserved quantities of ultimate interest, given the observed data.
3. Evaluating the fit of the model and the implications of the resulting posterior distribution. How well does the model fit the data? Are the substantive conclusions reasonable and do they make sense? Do the modeling assumptions greatly affect the results?

As determined by step 3, an analyst can alter or expand the model and then repeat the steps.

Markov Chain-Monte Carlo: Gibbs Sampling

For Bayesian analysis, the object is to obtain the posterior distribution, $p(\theta|y)$, from the prior distribution, $p(\theta)$, using the likelihood, $p(y|\theta)$. To accomplish this, by Bayes' Theorem,

$$p(\theta|y) = p(y|\theta)\, p(\theta) \,/\, p(y),$$

which says that the posterior distribution equals the likelihood times the prior distribution divided by the data. Because $\int p(\theta|y)\, d\theta = 1$ for $p(\theta|y)$ to be a "proper" probability density function, then

$$\int p(\theta)\, p(y|\theta)\, d\theta \,/\, p(y) = 1$$

and

$$1/p(y) \int p(\theta)\, p(y|\theta)\, d\theta = 1$$

and, therefore, $p(y)$ can be obtained by integrating, with respect to θ, over the likelihood times the prior or

$$p(y) = \int p(y|\theta)\, p(\theta)\, d\theta.$$

Thus, to finish Bayes' Theorem,

$$p(\theta|y) = p(y|\theta)\, p(\theta) \,/ \int p(y|\theta)\, p(\theta)\, d\theta,$$

or the posterior distribution is given by the likelihood times the prior normalized by all possible values of the likelihood times the prior.

Integration of $p(\theta|y)$ is often impossible due to the high dimensions (i.e., in the thousands) of the problem in the normalizing constant $\int p(y|\theta)\, p(\theta)\, d\theta$. That is, despite an ability to solve $p(y|\theta)$ and $p(\theta)$, computation of the denominator is impossible and, thus, $p(\theta|y)$ can only be "known" up to a value of p(y).

Methods exist to approximate $p(\theta|y)$ using Markov Chains to perform Monte Carlo simulation. The basic tenet of the methods is to draw a large sample, $\theta_1, \theta_2, \ldots, \theta_M$, from $\tilde{p}(\theta,y)$, where $\tilde{p}(\theta,y)$ is a good approximation to $p(\theta|y)$. Given a large enough sample from the simulation, $\tilde{p}(\theta,y)$ ought to look like a sample from $p(\theta|y)$. Creation of a Markov Chain with a stationary distribution equal to or similar to $p(\theta|y)$ should provide the desired $\tilde{p}(\theta,y)$, as illustrated in Figure 3.1.

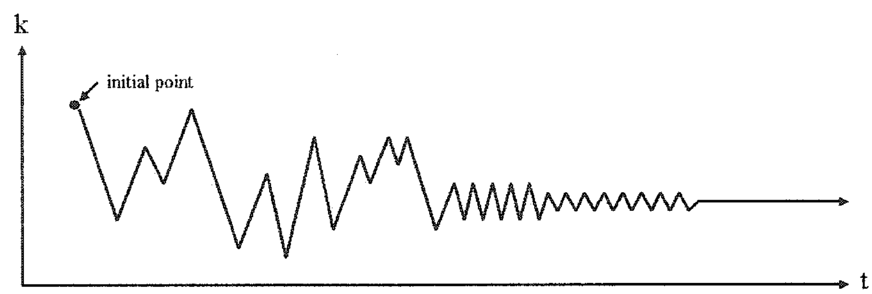


Figure 3.1. Markov chain

An example from discrete statistics is where $p(\mathbf{x}_t|\mathbf{x}_{t-1})$ equals the probability that the chain progresses to $\mathbf{x}_t$ given that it was last at $\mathbf{x}_{t-1}$. This probability is provided by a transition probability matrix (TPM). For example, a Markov Chain with three stages, $\mathbf{x}_1$, $\mathbf{x}_2$, and $\mathbf{x}_3$, the TPM might look like that shown in Figure 3.2. Given starting values with $\mathbf{x}_1 = -1$, $\mathbf{x}_2 = 0$, and $\mathbf{x}_3 = 1$, many iterations

going to

$$P = \begin{bmatrix} 0 & 0.2 & 0.8 \\ 0.6 & 0.1 & 0.3 \\ 0.3 & 0.3 & 0.4 \end{bmatrix} \quad \text{at}$$

Figure 3.2. Transition probability matrix (TPM)

are run, adjusting values of each x to construct a chain. The chain should, in theory, stabilize around a particular mean in time.

Although relatively simple for discrete statistics, for continuous statistics it is much more complicated. For continuous statistics, a sampling method called "alternating conditional sampling" or Gibbs sampling may be used. This method is defined in terms of subvectors (or individual parameters) of θ, $\theta = (\theta_1, \theta_2, \ldots, \theta_d)$, where d equals the number of parameters in the model. Each Gibbs iteration cycles thru each of the θ subvectors, drawing each subset conditional on the value of all others. Each iteration contains one step for each parameter.

In the case of the Gibbs sampler, the Markov Chain is also generated from a TPM. Instead of writing the TPM down, an equivalent approach is used (Casella and George 1992) that consists of drawing values of θ from its full conditional distribution or full vector.

Using a similar example to the TPM with three parameters θ_1, θ_2, and θ_3, the likelihood is $p(y|\theta_1,\theta_2,\theta_3)$ and the prior is $p(\theta_1,\theta_2,\theta_3)$ or $p(\theta_1)\, p(\theta_2)\, p(\theta_3)$, if independent. This leads to

$$p(\theta_1,\theta_2,\theta_3|y) \propto p(y|\theta_1,\theta_2,\theta_3)\, p(\theta_1)\, p(\theta_2)\, p(\theta_3) \text{ or } p(\theta_1,\theta_2,\theta_3,y),$$

for which the first part, $p(y|\theta_1,\theta_2,\theta_3)$, is the conditional distribution and the second portion, $p(\theta_1)\, p(\theta_2)\, p(\theta_3)$ is the marginal distribution. The full conditionals from this are $p(\theta_1|\theta_2,\theta_3,y)$, $p(\theta_2|\theta_1,\theta_3,y)$, and $p(\theta_3|\theta_1,\theta_2,y)$.

Using Gibbs sampling, four steps iteratively calculate θ's based on the full conditionals:

1. Start with a guess for θ_2 and θ_3, designated θ_2^0 and θ_3^0.
2. Draw θ_1^1 from $p(\theta_1|\theta_2=\theta_2^0,\theta_3=\theta_3^0,y)$.
3. Draw θ_2^1 from $p(\theta_2|\theta_1=\theta_1^1,\theta_3=\theta_3^0,y)$.
4. Draw θ_3^1 from $p(\theta_3|\theta_1=\theta_1^1,\theta_2=\theta_2^1,y)$.

The set $\{\theta_1^1,\theta_2^1,\theta_3^1\}$ represents the first Gibbs draw. To obtain many draws, iterate through the steps, beginning with step 2 by drawing θ_1^2 from $p(\theta_1|\theta_2=\theta_2^1,\theta_3=\theta_3^1,y)$. Repeat this many times to obtain multiple values of each θ, as shown in Table 3.1.

From the initialization point until some number of iterations have passed, the sampling does not reach a stationary distribution. This is the "burn-in" period. When the sampling reaches a stationary distribution, the burn-in period ends and sampling for draws that are retained can begin. The problem

Table 3.1. Theoretical Gibbs sampling results

Iteration	θ_1	θ_2	θ_3
1	θ_1^1	θ_2^1	θ_3^1
2	θ_1^2	θ_2^2	θ_3^2
3	θ_1^3	θ_2^3	θ_3^3
...	...	...	...
M	θ_1^m	θ_2^m	θ_3^m
...	...	...	...
M	θ_1^M	θ_2^M	θ_3^M

is determining the length of burn-in, which can be uncertain (Gilks 1998). Sometimes, to overcome this problem, burn-in is set at a sufficiently high number to ensure convergence. Performing a test run may also help determine burn-in prior to an actual run.

If, in the example, iteration **m** is assumed as the point where convergence is attained, then θ draws can be likewise assumed to be from a stationary distribution. Sampling then continues until iteration **M**, a stopping time defined by monitoring model convergence, to obtain adequate precision in the estimator. The longer the sampling run, the more confidence in the estimator precision. For this example, a sample of size **(M-m)** from $p(\theta_1|y)$, $p(\theta_2|y)$, and $p(\theta_3|y)$ is obtained. From these individual probabilities, statements of probability regarding the dependent variable can be made.

Finally, Gibbs sampling is effective when the full conditional has a standard form (e.g., normal, gamma, Poisson, negative binomial). However, if the full conditional for some parameters is not of a standard form, a different method is needed for sampling from that particular conditional. There are two possible alternatives:

1. Importance sampling: Sample from an "envelope" proposal distribution that approximates the actual distribution. Accept or reject the draw with a certain probability.
2. Metropolis-Hastings algorithm: This is also an accept or reject approach but one that generates a Markov Chain and with different assumptions about the proposal distribution. There are many different ways to implement Metropolis-Hastings but one common way is to use a random-walk Metropolis-Hastings algorithm.

Generalized Linear Models

A linear model can be written as follows:

$$\underline{y} = \underline{x}\underline{\beta} + \underline{\epsilon},$$

where $\underline{x}$ is a matrix of covariates with rows as the observations and columns as the variables, $\underline{\beta}$ is a matrix of parameters, and $\underline{\epsilon}$ is a matrix of error terms (SAS Institute 1999). Expanded, a linear model can be generalized as follows:

$$y_i = \beta_0 x_{0i} + \beta_1 x_{1i} + \ldots + \beta_k x_{ki} + \epsilon_i,$$

for i = 1, 2, …, n, where n equals the number of observations and k equals the number of covariates. β_0 is generally referred to as the intercept and the x_{0i}'s are usually assumed to equal 1.

The theory behind linear models is based on classical assumptions where, if exact experimental control is not possible (as is often the case), then tests must be interpreted as being conditional on observations (SAS Institute 1999). Additional assumptions include the following:

- The model form is correct (i.e., all important explanatory variables are included),
- Variables are measured without error and, thus, both the expected value of errors is zero and the variance of errors is constant across observations.
- The errors are uncorrelated across observations.

The assumption that the variance of errors is constant results in the assumption that the variance of the dependent variable is constant across observations. In addition, during hypothesis testing a Normal distribution is assumed for the errors. Regression analysis done on data not meeting these assumptions should be interpreted carefully, with a focus on exploration.

To fit a generalized linear model (GLIM), maximum-likelihood methods may be used. The class of GLIMs extends traditional linear models, allowing the mean to depend on a linear predictor through a nonlinear link function (SAS Institute 1999). GLIMs also allow the response probability distribution to be an exponential distribution. GLIMs are used when assumptions for a linear model are violated, e.g.,

- when a nonlinear relationship between $E(y|x)$ and x exists, even after a transformation,
- if the mean of the data is naturally restricted to a range of values,
- when an assumption of constant variance across observations is unrealistic, or
- when an assumption of normality is inadequate.

GLIMs extend the traditional linear model and are applicable to a wider range of analyses, including Poisson, binomial, and multinomial data analyses.

GLIMs have three primary components (SAS Institute 1999):

1. A linear component: $\eta_i = \beta \mathbf{x}_i$'
2. A link function that relates the linear predictor to the mean of the outcome (describing how the expected value of y_i is related to the linear predictor η_i): $g(\mu_i) = \beta \mathbf{x}_i$'
3. A random component specifying the distribution of y_i. These y_is are independent between observations and have an exponential probability distribution, implying that the variance of the response depends on the mean, μ_i, through a variance function, V: $\mathrm{var}(y_i) = \phi V(\mu_i)/\omega_i$.

The dispersion parameter, ϕ, is constant and either known or must be estimated, and ω_i is a known weight for each observation.

Response probability distributions for GLIMs, as previously mentioned, are of the exponential form. Two distributions of interest in traffic safety are the Poisson and the negative binomial. The Poisson distribution is useful for problems involving counts or "rare" events occurring in a given timeframe, such as traffic crashes (Carlin and Louis 2000; Gelman et al. 1998; Congdon 2001). The negative binomial distribution arises from a series of Bernoulli trials where the number of successes, rather than the total number of trials, is fixed at the outset. It is also used to model countable, infinite, random variables with variance much larger than the mean, making the Poisson model inappropriate. The negative binomial is the marginal distribution of Poisson random variables whose rate θ follows a gamma distribution.

If y is Poisson with mean μ, the response probability distribution is:

$$f(y) = \mu^y e^{-\mu}/y!,$$

with $\phi = 1$ and $\mathrm{var}(\underline{Y}) = \mu$. The link function is log, therefore $\mu = \exp(x\beta)$ or $\log(\mu) = \underline{x\beta} = \eta$ (SAS Institute 1999; Congdon 2001). However, the Poisson suffers from the potential for under- or overdispersion. If the dispersion, as measured by Pearson's χ^2, is not near 1 then the data may either be overdispersed (if χ^2 is greater than 1) or underdispersed (if χ^2 is less than 1), which means that there is variability in the data that exceeds the variability allowed by the sampling distribution (e.g., Poisson). To account for this, the variance function may be multiplied by the dispersion factor, ϕ: var(μ) = $\phi\mu$. Alternatively, a negative binomial distribution may be used in lieu of the Poisson to better model the data.

If y is negative binomial, the response probability distribution is:

$$f(y) = \Gamma(y+1/k) / \Gamma(y+1)\Gamma(1/k) \cdot (k\,\mu)^k / (1 + k\,\mu)^{y+1/k},$$

for y = 0, 1, 2, ... and where k is the dispersion factor and var($\underline{Y}$) = $\mu + k\,\mu^2$ (SAS Institute 1999). As is evident from the response probability distribution, the negative binomial is much more complex than the Poisson. For example, the dispersion parameter, k, in the negative binomial is not the same as ϕ but an additional parameter to be estimated or set to a fixed value. In addition, the link function for the negative binomial is more complex. Therefore, if the negative binomial can be achieved using Poisson as a basis, as it can using Bayes, then model simplification can be achieved while retaining advantages of the negative binomial.

One important aspect of GLIMs is selection of explanatory variables. Many types of explanatory variables can be used in GLIMs, including classification, continuous, interaction, and offset variables. Classification variables are variables that can assume only a limited number of discrete values, with the measurement scale for these variables being unrestricted. Some classification variables are unordered and are called nominal (e.g., collision type). Other classification variables have a definite order and are called ordinal (e.g., crash severity). Continuous variables can assume any range of values and are not limited to discrete values. Interaction variables are any combination of variables that, in a model, help assess mutual affects of variables. Offset variables are variables with a known regression coefficient. For example, in Poisson data where a mean count is expressed relative to exposure, the rate of occurrence per unit time, T, is an offset variable and can be included in the model using $\log(\mu) = \log(\lambda/T) = \log(\lambda) - \log(T)$. Taking $\log(\lambda) = \log(T) + \mathbf{x}\beta$ returns the usual Poisson formulation.

Changes in goodness-of-fit statistics can be used to evaluate contributions of each explanatory variable. Measurement of goodness-of-fit is generally achieved using the deviance, or twice the difference between the maximum attainable log likelihood and the actual log likelihood. SAS PROC GENMOD produces output indicating the deviances for the fitted model (SAS Institute 1999). Two other types of analyses for model fit can be output from SAS PROC GENMOD, "Type 1" analysis and "Type 3" analysis. The table for "Type 1" analysis summarizes twice the difference between each successive pair of models, indicating the additional gain in fit as variables are added. "Type 3" analysis indicates the contribution made by each additional explanatory variable to the model.

For interpretation, first consider the meaning of a unit change in **x** using standard linear regression. A unit change in **x** translates into a change in $\mu = E(y|x)$ equal to β. The change in μ is constant for all **x**. Using a GLIM, a unit change in **x** translates into a change in $g(\mu)$, which means the effect of a unit change in **x** depends on the value of **x**.

Using the Poisson example, $\log(\mu) = \mathbf{x}\beta$ and, therefore, $\mu = \exp(\mathbf{x}\beta)$. Effects of changes in **x** can be compared to a baseline. For baseline $\mathbf{x}_0$, the change in $\mathbf{y}_0 = g^{-1}(\mathbf{x}_0\beta)$. To obtain the effect of $\Delta\mathbf{x}$, $\mathbf{y} = g^{-1}(g(\mathbf{y}_0) \pm (\Delta\mathbf{x}\beta)$. Thus, GLIM interpretation is not as straightforward as for standard linear models.

The Bayesian approach to GLIMs can be either hierarchical or non-hierarchical. For non-hierarchical models, the priors for β are indexed by known parameters, or parameters that have been fixed or estimated. For hierarchical models, the priors for β depend on further unknown parameters with their own priors (e.g., overdispersed models). Elaborating on this, for overdispersed models, a prior can be placed on ϕ, resulting in $p(\beta,\phi) = p(\beta|\phi)p(\phi)$ or $p(\beta)p(\phi)$. This allows variability within the model, fitting with consideration of the uncertainty about the value of ϕ.

Challenges in the Bayesian Approach to Data Analysis

An impediment to using Bayesian methods is the perception of a need for large amounts of data. Though Bayesian methods facilitate the use of large amounts of data, there is no requirement for large amounts of data. Bayesian methods can get by with no more data than current SICL methods. The results of Bayesian analyses using such data would be as informative (or uninformative) as those resulting from current SICL methods (with means, variances, and other standard statistical information), with the addition of some special Bayesian properties such as the ability to obtain distributions over types of sites (e.g., sites: uncontrolled, two-way stop, four-way stop, signalized) and, therefore, the ability to compare across and between these types. Comparisons of means, variances, and further drill-downs into other explanatory variables within each category can be developed.

The initial model development process may be an arduous task. Implementation of the Bayesian approach requires the assignment of probability distributions both to the data (**y**) and the parameters (θ) (Carlin and Louis 2000). Practitioners familiar with frequentist statistics may find this disconcerting. In addition, part of the prior knowledge is generally the assignment of an assumed distribution (π), much like the likelihood methods. Bayesian analysis takes this prior knowledge, quantified by our assignment of an assumed distribution (π) that includes our assessment about the parameters (θ), and updates it using the data via Bayes' Theorem. The resultant posterior distribution blends the information provided by the data and the prior. Clearly, all this might be somewhat confusing and uncomfortable for unfamiliar analysts. In fact, determination of the prior distribution (π) and, perhaps, the hyperprior distribution has been a major impediment to use of Bayes. These distributions are typically specified based on results from past studies or from expert knowledge. However, if few prior analyses have been done, it is difficult to build upon this. Fortunately, experimenters can streamline this process and simplify computations by specifying the prior distribution (π) from a common distributional family (e.g., Poisson, negative binomial, gamma). Another option is to construct a fairly non-informative prior distribution (π). A non-informative prior distribution allows the data to dominate the specification of the posterior distribution. Finally, despite the rigor involved, the results of Bayesian methods are not only more informative but also generally more easily interpretable.

Another major impediment of Bayesian methods is that, for statistical models of even moderate complexity, the integrals involved in the analysis are not tractable in closed form (Carlin and Louis 2000). Recently developed methodologies that are designed to utilize computing advances have largely solved this problem. Sampling-based methods enable estimation of hyperparameters and computation of posterior distributions (e.g., Markov Chain–Monte Carlo as represented by the Gibbs sampler) (Casella and George 1992).

Empirical Bayesian methods have many of the same problems but also introduce unique problems. EB requires more data because a large group of reference (or comparison) sites are required (Pendleton 1991; Pendleton et al. 1991; TRB 2001b). This requirement of reference (or comparison) sites is akin to the sites required for quality control methods. The reference (or comparison) sites for each analysis must be fit into categories, which can be difficult and cumbersome to define. The categorization limits the flexibility of analyses by limiting an analysis to that particular type of site, not allowing for comparison between sites. Hierarchical Bayesian methods avoid this.

As previously mentioned, EB methods use crash data to define prior and the posterior distributions. This tends to overestimate the confidence of the posterior, requiring corrections. That is, because no allowance is made for the uncertainty in the variance, EB methods underestimate the variability in the model and EB confidence intervals are too narrow, thus overconfident (Gilks 1998). Hierarchical Bayesian methods, if conducted properly, do not have this limitation.

In the traffic safety field, EB methods have existed for some 20 years (Pendleton 1991). Multiple software development efforts have been made (Pendleton et al. 1991) or are in process (MRI 2002a,b,c,d,e,f,g;2003a,b,c,d,e), but use by practitioners is limited. Lately, researchers have begun to use hierarchical Bayesian methods more (Davis and Yang 2001; Melcher et al. 2001), and the development of hierarchical Bayesian software has progressed (BUGS 2003).

Advantages of the Bayesian Approach to Data Analysis

The Bayesian decision-making paradigm makes the following improvements to the frequentist statistical analysis approach (Carlin and Louis 2000):

- A more philosophically sound foundation
- A unified, streamlined approach to data analysis
- An ability to formally incorporate prior knowledge or opinion via the prior distribution

Practitioners are now, due to increased familiarity and availability of computational tools, increasing the use of Bayesian methods as traditional analytic methods prove both theoretically and practically inadequate.

It is clear that larger sample sizes lead to more reliable inference, but this applies to both Bayes and non-Bayes methods. However, the unified, streamlined approach mentioned previously lends itself to the easy inclusion of additional information into a Bayes model. In certain areas there is a wealth of data; in others there is little data. Bayesian methods are particularly well suited to the latter, since they do not rely on asymptotic theory. Bayesian methods create an effective framework for inclusion of crash and non-crash data into statistical modeling and development of a safety improvement candidate location ranking list. Frequentist methods are more cumbersome in this regard.

As mentioned above, frequentist methods rely on large samples. However, at least in theory, hierarchical Bayesian methods could be used to develop results with very limited data. This indicates another advantage of Bayes: With little data, Bayesian methods can outperform frequentist methods, assuming that good prior information is available. Sites that have no data for certain parameters or attributes can be readily included in Bayesian analysis.

A typical Bayesian analysis could report findings based on a summary of a variety of information regarding the posterior distribution (Carlin and Louis 2000). These findings include the mean and mode, important percentiles (e.g., probability levels 0.025, 0.25, 0.50, 0.75, and 0.975), a distribution plot that would show whether the posterior distribution of interest is multimodal, skewed, or otherwise of concern, and probabilities that a certain value (defined previously) is contained within the distribution (Carlin and Louis 2000; Gelman et al. 1998).

Bayesian methods can also provide more output data than frequentist methods. That is, in addition to providing the standard statistical results (e.g., means, variances, standard deviations), Bayesian methods provide analogues to common frequentist techniques such as point estimation, interval estimation, and hypothesis testing (Carlin and Louis 2000). The Bayesian analogue of a frequentist confidence interval is a credible set. A credible set enables direct probability statements about the likelihood of a value falling in the set. For example, an analyst could assess the probability that a certain condition existed at a site given the number of crashes of a certain type occurring at a site. Frequentists would have to have a large number of data sets that had precisely the same information and could then only assess the percentage of sites that might contain the same condition. This frequentist interpretation relies on the concept of a "large number" (Carlin and Louis 2000), which is often infeasible given the nature of crash data. The interpretation of a Bayesian credible set is much more straightforward than that of a frequentist confidence interval.

Bayesian methods provide information about how sites and groups of sites compare to one another, both by providing information about each site or groups distribution and by enabling an assessment of how much worse one site or group might be than another. Within a group (e.g., four-way, stop-controlled sites), Bayesian results provide the ability to assess whether a particular site is significantly worse than the average for sites of its type. Between groups (e.g., sites in general), Bayesian results enable determination of which group is of more concern. Also, both for sites and for groups, Bayesian results provide the probability that a certain site or group would have a certain level of crashes. This enables an analyst to assess how much worse a site is as compared to another. The same holds true for groups. Hierarchical Bayes allows for the assessment of heterogeneity both within and between groups (Carlin and Louis 2000). This facilitates both the common reactive approach to transportation safety and the more attractive proactive approach.

Bayesian methods also simplify the concept of hypothesis testing (Carlin and Louis 2000). Bayesian hypothesis testing is more sensible in principle. Based on the data that each hypothesis is to predict, application of Bayes' Theorem allows computation of the posterior probability that the first hypothesis is better supported by the data and prior information. Also, there is no limitation on the number of hypotheses that can be considered simultaneously. These multiple hypotheses do not need to be nested, and the Bayes factor is precisely the odds in favor of one model or hypothesis given the data alone.

Frequentist hypothesis testing, in contrast and despite its long history, has several shortcomings. First, the competing hypotheses must be nested; that is, H_0 must normally be a subset of H_a, accomplished by setting one of the parameters of H_a to some constant (Carlin and Louis 2000). However, many practical hypotheses do not fit the nesting concept (e.g., Is site X worse than site Y?) Second, classical hypothesis tests can only compare against the null hypothesis (e.g., Is site X above average?). A small p-value indicates that the alternative model has significantly more explanatory power; however, a large p-value does not suggest model equivalence but simply that there is no evidence that the models differ. Third, p-values offer no direct interpretation of level of evidence but only indicate that, in the long-term if the situation continued as recorded, the data obtained would be the same (e.g., If site X had 10 crashes on average for the past 5 years, it will have 10 crashes on average in the next 5 years). Finally, as p-values depend not only on the observed data but also the total sampling probability of certain unobserved data points, the p-values resulting from two experiments with identical likelihoods could be different if the experiments were designed differently. This violates the likelihood principle, which essentially states that all relevant experimental information is contained in the likelihood function for the observed y after y has been observed. Thus, the p-values should not differ. The Bayesian approach overcomes all four of these difficulties.

Inclusion of prior knowledge is a significant advantage for Bayesian methods as well, freeing analysts from ad hoc adjustments to results that seem wrong (Carlin and Louis 2000). Though frequentist methods include prior knowledge insomuch as a frequentist would have to specify a distribution function for the likelihood, frequentists don't test their assumption of a distribution as directly as Bayesians. This is due to the fact that frequentists assume that their distribution parameters are fixed, whereas Bayesians assume the distribution parameters are random and condition them using the data. The advantage of including prior knowledge is that an analyst can include knowledge previously gained about a situation (e.g., expert knowledge) and apply it to the current situation. Frequentists can only do this by assuming a distribution that has been previously tested. In transportation safety practice the distribution normally assumed is Poisson, but lately there has been greater use of negative binomial. Frequentist methods have no mechanism for adjusting the distributions, whereas Bayesians do. In addition, frequentists have no mechanism for inclusion of the results of previous analyses into current analyses. Bayesian theory is predicated on this. Therefore, the more analyses an analyst performs, the more prior information for subsequent analyses will exist. In fact, hierarchical Bayes facilitates meta-analysis, the combining of information from several published studies. This type of analysis has been conducted more frequently as of late, with some applications in the area of transportation safety (Elvik 1998; Elvik and Mysen 1999).

The only potential advantage of EB over hierarchical Bayesian is the fact that, in the transportation safety community, EB is more developed, having been extensively discussed and used over the past 20 years by many prominent researchers. Software for EB has been developed over that time (Pendleton et al. 1991), and there is a current effort to create a more user-friendly, comprehensive EB software (MRI 2002a,b,c,d,e,f,g;2003a,b,c,d,e). However, this is also true of hierarchical Bayesian methods and any advantage of EB over hierarchical Bayesian methods is lessening.

CHAPTER 4. THE STATISTICAL MODEL

Model development begins with specification of the independent variable, crash frequency, and the primary dependent variable, crash rate. Volume, in terms of daily entering vehicles (DEV), is treated as an offset variable used in the calculation of crash rate. This is a standard treatment of exposure in Poisson models (Gelman et al. 1998; Carlin and Louis 2000; Congdon 2001; Gilks 1998). In model terms, these data elements are represented as follows:

y_i = crashes frequency at i^{th} site during study period ≥ 0

ν_i = traffic volume entering i^{th} site during study period (DEV) ≥ 0

λ_i = crash rate at i^{th} site during study period ≥ 0

Also, from traffic engineering principles (ITE 1992):

crash rate, $\lambda_i = y_i/(\nu_i$ x days in a year x years) x 1,000,000

for intersections, where crash rate is expressed in terms of crashes per million entering vehicles (MEV). The constants may be dropped for model convenience, making the crash rate, $\lambda_i = y_i/\nu_i$. Conversely, the crash frequency can also be calculated by rearranging the equation:

crash frequency, $y_i = \lambda_{i(}(\nu_i$ x days in a year x years) / 1,000,000.

Again, the constants may dropped for model convenience, making the crash frequency, $y_i = \lambda_i\nu_i$. This equation provides a basis for model selection and development.

Both the crash frequency and the volume are positive count variables, as indicated. Therefore, the rate must be a positive number. The study period for this research is one year, 1998. Multiple years are not considered in this model, though they could be added.

A variety of site characteristics (e.g., controls, geometry, speed limits) covariates are included, based on the data collected at each site. These covariates were used in the model, along with the volume, to estimate the crash rate, λ_i, for each intersection. In model terms the covariates were represented as follows:

$\underline{x}_i$ = vector of covariates, or site characteristics, for i^{th} site; thus $\underline{x}_i' = [x_{1i,} x_{2i}, \ldots, x_{pi}]$, where p is the number of covariates.

Each of these covariates has a regression parameter or slope associated with it. These regression coefficients provide an indication of the relative strength or importance of the variable in the model. Unit changes in variables with greater strength have larger effects on the crash frequency and rate. The covariate parameters are represented in the model as follows:

$\underline{\beta}$ = vector of covariate parameters, or slopes; thus $\underline{\beta}' = [\beta_1, \beta_2, \ldots, \beta_p]$.

Covariates and covariate parameters are both represented as matrices. Each site will, using these definitions, use the same covariate parameters.

As defined here, the response variable is crashes, y_i, at an intersection and the causal variables are traffic volume, ν_i, and crash rate, λ_i. These causal variables, when multiplied, result in crashes at the intersection. The site characteristic covariates, $\underline{x}_i$, factor in site differences and similarities, adjusting the response variable appropriately. In model terms,

$$y_i \mid \nu_i, \underline{x}_i \sim \textbf{Poisson}\ (\lambda_i).$$

That is, each site's crash frequency, given the site volume and the site characteristics, is distributed as a Poisson random variable with the crash rate as the mean. The Poisson distribution was chosen because it is the appropriate distribution for positive counts, fitting the nature of crashes.

The negative binomial distribution is also appropriate for positive counts. Unlike the Poisson, it provides for possible overdispersion, or unequal mean and variance. One way to overcome this limitation of the Poisson distribution is to formulate the model in a hierarchical manner, by letting λ_i (or some function of λ_i) be a random variable with its own distribution. The hierarchical Bayesian framework permits this by including uncertainty about the mean and variance of the rate. This treatment is more flexible than setting the distribution to negative binomial by fiat because the data have greater influence on the resultant posterior distribution. We proceed to writing the model in a hierarchical manner below.

Given the volumes, ν_i, and the site characteristics, $\underline{x}_i$, for each site, the crash rates, λ_i, for each site need to be estimated. To estimate the crash rate, λ_i, for each site, an equation that relates the volumes, ν_i, and site characteristics, $\underline{x}_i$, to the crash rate, λ_i, is developed. As stated previously, $y_i = \lambda_i\nu_i$ to relate crash frequency, the dependent variable, to site characteristics. We formulate a linear model. Because crash rate always has to be positive, we postulate that the log crash rate is a linear function of site characteristics and log volume, as follows:

$$\log(\lambda_i) = \log \nu_i + \beta_0 + \underline{\beta}' \, \underline{x}_i.$$

where β_0 is the intercept term, which can be interpreted as the effect of volume alone.

Using a log transformation for λ_i constricts the results to non-negative values only, which fits the nature of both crash frequency and volume. Normally, there would be an error term, ϵ_i, as well. In our case, we considered only one observation per intersection and thus an error term would have led to lack of identifiability in the model.

Given the preceding, the resultant likelihood function for crash frequency, y_i, is developed:

$$[y_i \mid \nu_i, \underline{x}_i] = \frac{(\lambda_i v_i)^{y_i}}{y_i!} \exp\{-\lambda_i v_i\},$$

which can be interpreted as the crash frequency, y_i, at site i, given both the volume, ν_i, and the site characteristics, $\underline{x}_i$, are equal to the individual frequencies at each site, $(\lambda_i v_i)^{y_i}$, averaged over all sites and multiplied by the calculated frequencies based on the site characteristics, $\exp\{-\lambda_i v_i\}$. Because the term in the denominator, $y_i!$, of the likelihood equation does not depend on any of the parameters (i.e., λ_i, v_i, and $\underline{x}_i$), it is considered a constant. Therefore, applying proportionality ($\propto$) simplifies the equation:

$$[y_i \mid \nu_i, \underline{x}_i] \propto (\lambda_i v_i)^{y_i} \exp\{-\lambda_i v_i\}.$$

Once all individual site characteristics have been accounted for, whatever remains is applicable to all sites. That is, assuming all sources of difference between sites has been accounted for, by proper choice of covariates or influential site characteristics, whatever remains will apply to every site. At this point, a joint likelihood, for a number (n) of independent identical draws (i.i.d), is constructed:

$$[\underline{y} \mid \underline{\nu}, \underline{x}] \propto \Pi^{n}_{i=1} (\lambda_i \nu_i)^{y_i} \exp\{-\lambda_i v_i\}.$$

This joint likelihood simply adds the product operator to the model, which effectively applies the model over all sites.

Up to this point, everything that has been done is equally applicable to classical/frequentist methods and Bayesian methods. That is, both methods progress from model definition to development of a joint likelihood. Further development of this joint likelihood is the point at which the methods diverge, beginning with a fundamental difference in philosophy.

Classical methods assume a distribution for the data, and the procedure is to integrate over the data distribution and take an average, assuming that the sample represents an infinite population with the same characteristics. Using classical methods, one might use maximum likelihood estimators (MLEs) of the β's and λ's to obtain a point estimator (within a range).

Bayesian methods contend that the results depend on the actual sample that was obtained. Everything is conditioned on the data obtained (i.e., sampled); no assumption of an infinite population is made. Bayesian methods add a layer to a model. The parameters (β's and λ's) are assumed to be random. There is no such thing as a "truth" or fixed and unknown parameter values to be estimated. Instead, one obtains a distribution of (β's and λ's) by calculating the posterior distribution of the parameters, based on the data. Once this distribution has been obtained, one can calculate a point estimator, as if using classical methods. However, Bayesian methods provide much more information due to the resultant distribution of the parameters. In addition, the determination of the model parameters for one set of sites enables the use of the inferences gathered as prior information for another group of sites.

To continue using a Bayesian approach, a set of priors must be developed based on a best "guess" of the values. These values are assigned, much like the β's, a variance that denotes the level of confidence in the value. Essentially, the values are treated as random variables as well, to the extent that the variances are left large. Setting $\theta_i = \log(\lambda_i)$, it can be stated that $[\theta \mid \mu,\sigma^2] = \Pi^n_i [\theta_i \mid \mu_i,\sigma^2]$. This is interpreted as the overall rate given the mean and variance, $[\theta \mid \mu,\sigma^2]$, is the product of the individual site rates given the individual means and variances, $\Pi^n_i [\theta_i \mid \mu_i,\sigma^2]$. θ is given a normal distribution due to the linear model above. The individual site mean in this equation, μ_i, is determined by multiplying the matrix of the individual site covariates, $\underline{\mathbf{x}}'_i$, to the matrix of overall site covariate parameters, $\underline{\beta}$, which is denoted by the following:

$$\mu_i = \underline{\mathbf{x}}'_i \underline{\beta}.$$

The individual site rate, θ_i, given the individual site mean, μ_i, and the overall variance, σ^2, is proportional to the inverse of the standard deviation, σ^{-1}, multiplied to the exponential of the product of the inverse of two standard deviations, $-1/2\sigma$, and the square of difference between the individual site rate, θ_i, and the individual site mean, μ_i:

$$[\theta_i \mid \mu_i,\sigma^2] \propto \sigma^{-1} \exp \{-\frac{1}{2\sigma} (\theta_i - \mu_i)^2\}.$$

Therefore, the log transformed rate, log (λ_i), is distributed as a Normal distribution with mean equal to $\underline{x}_i'\underline{\beta}$, the individual site means, and variance equal to σ^2, the overall variance. Therefore, log (λ_i) = θ_i, as shown:

$$\log (\lambda_i) \sim N(\underline{x}_i'\underline{\beta}, \sigma^2); \text{ therefore, } \log (\lambda_i) = \theta_i.$$

However, the β's and σ's still must be dealt with. These two values are referred to as hyperpriors in the Bayesian method. The β_j's, where j = 1, ..., p with p equal to the number of covariates, are assumed to be distributed as Normal with a mean of 0 and a variance of 1000, which is much larger than any anticipated β_j. These assumptions are made to reflect a lack of knowledge about or lack of confidence in the true value for each β_j. That is, the prior values of the β_j are set so that each β_j can take on any value, as defined by the data rather than any prior knowledge. If, instead, some knowledge of the true value were available, this value could be inserted as the mean and the variance could be adjusted to reflect the confidence in this knowledge. However, in this case, the values have been set with an initial "guess" of 0 and a variance sufficient to allow the true value to be discerned through running the model. The distributions of the β_j's are represented as follows:

$$\beta_j \sim N(0,1000).$$

To consider the variance, σ^2, a gamma, Γ, distribution is used as a starting point because it is a standard variance distribution. In addition, Γ is positive only, which fits the data. Therefore, the distribution becomes

$$\sigma^{-2} \sim \Gamma(a/b,a/b^2),$$

with a and b greater than 0.

In this model, the values of λ_i and, subsequently, σ^{-2} are allowed to vary, transforming the initial Poisson model assumption to a negative binomial and accounting for possible overdispersion in the data. That is, if the model, $y_i \mid \nu_i, \underline{x}_i \sim$ **Poisson** (λ_i), had remained set with a fixed λ_i, not setting log $(\lambda_i) \sim \mathbf{N}(\underline{x}_i'\underline{\beta}, \sigma^2)$, then the model would have remained Poisson. Here, (y_i, λ_i) have a joint distribution induced by the second level of the hierarchy. In this case, the marginal distribution of y_i, obtained by integrating out λ_i from the joint distribution can be shown to be in the negative binomial form. Therefore, any possible under- or overdispersion is accounted for.

In mathematical terms, this can be represented as follows:

initial model: $y_i \mid \nu_i, \underline{x}_i \sim$ **Poisson** (λ_i),

where λ_i is assumed to represent the mean and the variance, as per the Poisson distribution. However, with further model refinement,

$$\log(\lambda_i) \sim \mathbf{N}(\underline{x}_i'\underline{\beta}, \sigma^2),$$

which states that λ_i is allowed to vary as a Normally distributed variable with mean equal to a function of the covariates, $\mu = f(\underline{x}_i'\underline{\beta})$. This leads to the probability of y represented as follows:

$$p(y_i) = \int p(y_i, \lambda_i)\, d\lambda,$$

which introduces extra variability into the model through an expression of uncertainty in λ. Therefore, a hierarchical Poisson, as constructed for this application, equates to a negative binomial that is more flexible than an assumed negative binomial distribution.

For σ^{-2}, two new hyperpriors (a and b) have been introduced, which must be dealt with. A good value for the mean, or prior guess, of σ^{-2} is the inverse of the observed variance of $\ln(y_i/\nu_i)$ (i.e., the variance from the data) because $a/b^2 = a/b * 1/b = E(\sigma^{-2}) * 1/b$. The value of b is set small to get a large prior variance because the true value is unknown. Thus, the model is relied on more heavily, as opposed to any prior guess.

Finally, the full model is developed:

$$[y,\theta,\underline{\beta},\sigma^{-2}] \propto \Pi^n(\lambda_i\nu_i)^{y}{}_i \exp\{-\lambda_i\nu_i\}\sigma^{-1}\exp\{-\tfrac{1}{2}\sigma^{-2}(\theta_i - \mu_i)^2\}(\sigma^{-2})^{a-1}\exp\{-b\sigma^{-2}\}\Pi^p{}_{j=1}N(\beta_j;0,1000).$$

The full model results from putting all the following pieces together:

- $\Pi^n (\lambda_i \nu_i)^{y_i} \exp\{-\lambda_i \nu_i\}$ is from the data and should be transformed to θ_i,
- $\sigma^{-1} \exp\{-(1/2)\, \sigma^{-2} (\theta_i - \mu_i)^2\}$ is the prior for θ_i,
- $(\sigma^{-2})^{a-1} \exp\{-b\sigma^{-2}\}$ is the prior for σ^{-2}, resulting from the expansion of the Γ, and
- $N(\beta_j;0,1000)$ is the prior for β_j.

A simpler version of this model omits one source of variability in the λ_i. Consider the following, two-tier, hierarchical model:

$y_i|\nu_i \sim$ **Poisson** (λ_i,ν_i)

$\lambda_i = \underline{x}_i'\underline{\beta}$

$\beta_j \sim N(\mu_\beta,\sigma^2_\beta)$

where, implicitly, σ^2 in the full model is set to zero. Thus, uncertainty in the value of λ_i derives from uncertainty about the value of the regression coefficients. The results of this research were obtained from fitting the two-tiered, hierarchical model.

CHAPTER 5. METHODOLOGY

To achieve the research objectives, an appropriate methodology was developed. This methodology included specification of the model form, data needs identification, and model refinement through data collection, exploration, and updates to model application and output evaluation and interpretation. These steps are detailed in the following sections.

Initial Model Form Development

An initial model was based on knowledge of the nature of the problem. It did not consider specifics of all potential covariates but only the dependent variable (i.e., crash frequency) and primary independent variables (i.e., rate and volume). This model represents the intersection characteristics (i.e., additional independent variables) as arrays containing an indeterminate number of slopes (**β**s) and covariates (**x**s). A model form might be $f(\mathbf{y}_i = \boldsymbol{\beta}_0 + \underline{\boldsymbol{\beta}}\,\underline{\mathbf{x}} + \boldsymbol{\varepsilon})$, where $\mathbf{y}_i$ is the dependent variable, $\boldsymbol{\beta}_0$ is the intercept term, $\underline{\boldsymbol{\beta}}\,\underline{\mathbf{x}}$ are arrays containing the slopes and covariates, and ε is an error term.

As previously noted, crashes are often modeled as either Poisson random variables or negative binomial (NB) random variables. This choice is due to the nature of crashes as rare, positive count events at any one point. Both the Poisson and the NB distributions are appropriate probability models for count data. The NB model allows for overdispersion of observations, whereas the standard Poisson model, with equal mean and variance, does not. Thus, the NB model is often preferred for analysis (Harwood et al. 2002; Mitra et al. 2002; Saccomanno et al. 2001).

In this study, the Poisson model is formulated in hierarchical form, to allow for overdispersion. A Poisson distribution was chosen as the first-level probability model for crash frequencies. However, inclusion of uncertainty concerning the Poisson mean via the second-level model accommodated potential overdispersion. Thus, while the first-level model was Poisson, the full hierarchical model was NB.

The relationship of frequency to rate and volume were considered in selection of the statistical distribution and mathematical functions used to equate the variables and develop the joint likelihood function. Using this knowledge and the potential inclusion of multiple intersection characteristic variables, a theoretical model was developed. Development progressed from assumption of distribution through joint likelihood function development to full Bayesian model completion.

Identify Data Needs

Once the theoretical model form was completed, available data were assessed based on model constraints (e.g., consideration of variables on a total intersection basis). Data needs included crash frequency and volume at each site. Review of literature related to intersection safety and design and engineering knowledge of the topic were used to decide which other data categories to include.

Previously compiled data, both electronic and paper records, were examined. Evaluation of both the extent and validity of current data was required. Two Iowa databases contain data related to crashes and road characteristics: the Iowa historical crash database and the roadway inventory database, known as the Geographic Information Management System (GIMS).

The Iowa historical crash database contains "statistical" crash data for crashes covering the decade from 1991 through 2000. These data were collected using Iowa's former crash reporting form (the crash reporting form was revised, effective January 2001). Statistical crash data include Iowa crash report form data not defined as legally protected private information. Examples include the following: various severity measures (e.g., crash and injury severity), location and time variables, crash type indicators, driver and vehicle characteristics, road characteristic and road condition data, and injured person details.

For crashes prior to year 2000, crash locators from the Iowa DOT Motor Vehicle Division (MVD) located the crashes using Iowa's quasi-coordinate link-node system (Goolsby and Yu 1975). This system was used to assign a unique intersection identifier value if a crash was related to an intersection. Using these intersection identifier values, crash data were gathered for each intersection of interest. The crash data collected include frequency, severities, and property damage.

The GIMS database primarily consists of data collected and stored in segment-based representation. No specific intersection database for Iowa currently exists. The GIMS database used for this research was the 1999 snapshot, or data representing the road conditions at the end of year 1998. Review of the segment database was carried out to evaluate the possibility of using the segments to develop an intersection representation. Because the segment database represented intersection geometric data poorly, site visits were required for collecting the intersection data. Volume data for each approach were obtained from the GIMS database.

Both the crash database and the GIMS database attributes were tied to spatial representations. This enabled use of a geographic information system (GIS) for volume data collection and input, which minimized the time and effort required for this portion of the data collection.

Data not contained within accurate, inclusive databases were obtained by other means. The primary method was the site visit to obtain intersection geometric and site safety data. Data collected include control, geometrics (e.g., number of lanes, type of lanes), travel direction, topography, intersection class, land use, speed limits, and surface type.

The data collected included 1031 Ames (221) and Des Moines (810) intersections. The initial Ames intersection characteristic data was collected during 1998. Des Moines intersection characteristic data was collected as part of an Iowa DOT project during 2001. The crash frequency data for all sites was from year 1998. The discrepancy between the Des Moines intersection characteristic data timeframe and the crash frequency timeframe was considered inconsequential given the macro level of the model and the relative stability of the sites visited.

Final Model Development

The final model fully defined each variable to be considered, including covariates as determined by the data needs assessment. The initial model was expanded to define each covariate (e.g., $\boldsymbol{\beta}' \underline{\mathbf{x}}_i$ was expanded to $\boldsymbol{\beta}_1\mathbf{x}_1 + \boldsymbol{\beta}_2\mathbf{x}_2 + \ldots + \boldsymbol{\beta}_i\mathbf{x}_i$). Crash frequency was the dependent variable with crash rate as the primary independent variable. Volume was treated as an offset variable within an equation relating the crash rate to volume and intersection characteristics. This model was used for statistical analysis purposes and statistical software manipulation but had little impact on data collection.

Data Collection

Using Iowa's Safety Analysis, Visualization, and Exploration Resource (SAVER), a map depicting roads, rivers, rail, and crashes, was developed, as shown in Figure 5.1. SAVER was

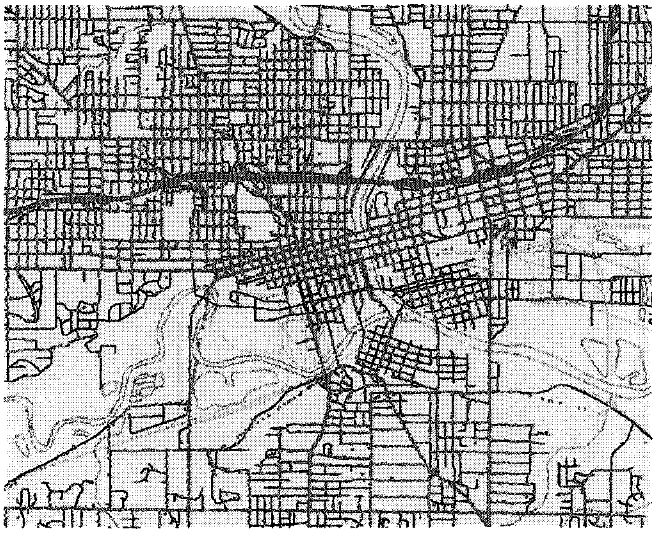


Figure 5.1. Crash and GIMS data map

constructed within a GIS environment, which enables use of spatial relationships to connect data. The following attributes were tied to the spatial features of each database: crash frequencies, severity indicators, and volume data. SAVER had no simple mechanism to aid in the collection of the data for this research. Instead, three data collection and entry tools were developed for volume input, intersection characteristic input, and crash data collection. Two additional tools were developed to facilitate site location. Scripts written to operate the tools are shown in Appendix G.

Volume and direction input tool

The volume and direction input tool, shown in Figure 5.2, contains three control panels and

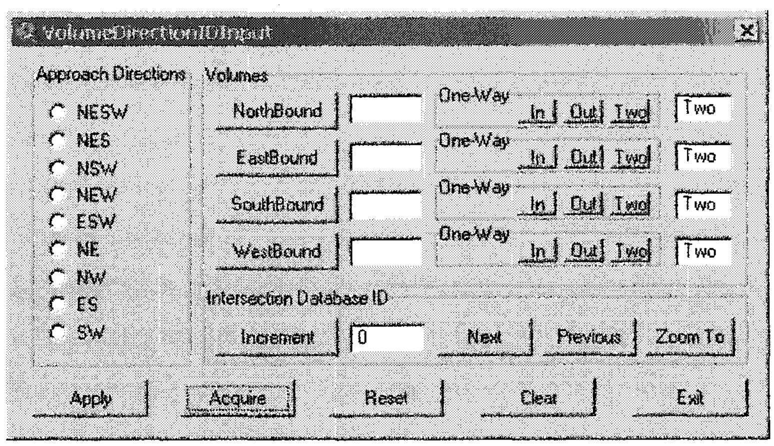


Figure 5.2. Volume and direction input tool

several buttons. These controls allow selection of approach directions, collection of volumes and travel direction (e.g., two-way or one-way in or out) for each approach, and switching between intersections. The buttons along the bottom can be used to apply entered data, acquire previously entered data, reset the dialog and the current intersection data, clear the dialog, and exit the dialog. The intersection corresponding to each identifier (ID) is displayed on the map when it is incremented.

Intersection site visit input tool

The intersection site visit input tool, shown in Figure 5.3, contains several control panels and buttons. This tool was designed to input the site characteristics after aggregation. The control panels consist of radio buttons, which limit selection to only one choice per control panel (i.e., variable type). A control panel for identifying an offset T intersection pair is included. Finally, the controls

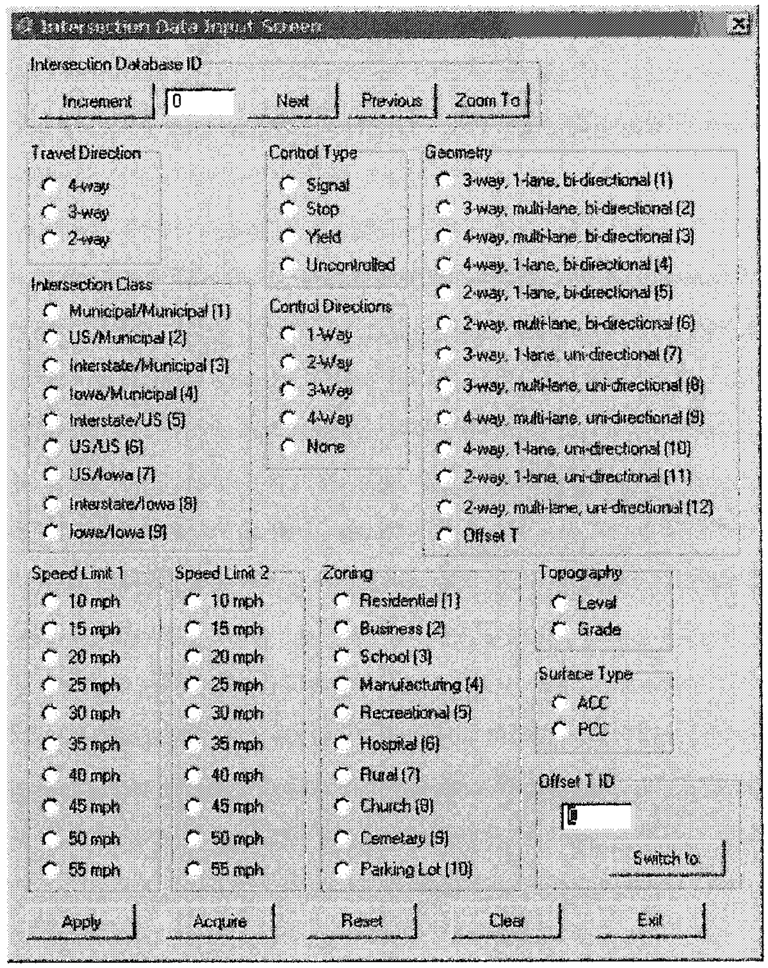


Figure 5.3. Intersection site visit input dialog

for switching intersections and applying, acquiring, resetting, clearing, and exiting again appear. The "Zoning" control panel should be title "Land Use" to reflect the data.

Crash data collection script

For collection of crash data (i.e., site crash frequency and severity indices), a script was coded. Using the quasi-coordinate node-link designation for each intersection, the crash data for each intersection were compiled and inserted into the master intersection data collection database.

Intersection searcher tool

The searcher tool, shown in Figure 5.4, enables searches for individual intersections, both within the database and on the map. Intersection searches begin with entry of portions of cross street names

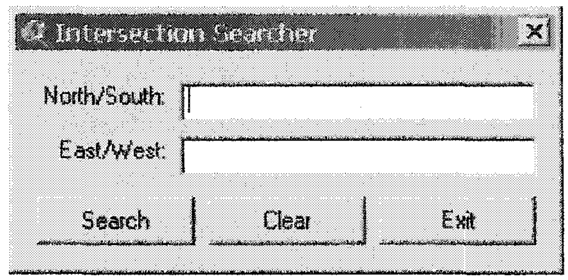


Figure 5.4. Intersection searcher dialog

(e.g., “Main” for “E. Main St.”). Selecting the search button locates the intersection and displays the intersection on the map. This tool is used in conjunction with the other tools.

Zoom tool

Shown in Figure 5.5, the zoom tool organizes the existing zoom tools within the GIS

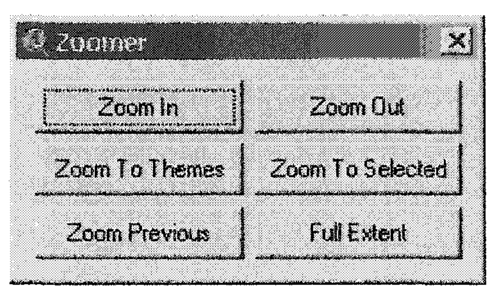


Figure 5.5. Zoom tool

environment. The buttons are tied to the existing scripts for each zoom operation.

Data collection and entry feature usage

Each of the first four tools depends on an existent intersection database, which must be linked to a map layer. The intersection database was constructed using standard GIS functionality, one column for each of the variables: intersection identifier, north/south street, east/west street, crash database intersection node number, crash frequency, volume, each of the covariates, and the other data collected using the tools. North/south street, east/west street, and crash database intersection node number were entered, one set for each intersection. Then each intersection was linked to a mapped intersection point. Finally, an intersection identifier was assigned.

Volume and direction data collection and input

Using the volume and direction input tool and the intersection searcher tool, each intersection was identified and its data were entered. The intersection searcher tool was used to identify each intersection, both within the database and on the map. The volume and direction input tool was then used to enter intersection approach directions, approach volume, and travel direction. The approach directions were defined in terms of travel direction (e.g., E equals "eastbound") because the interest was in what enters the intersection, rather than what departs from it. The appropriate directional radio button was selected, considering intersection skew as needed. This selection affects data entered into the database for volumes and travel direction. To collect volumes, each approach to the intersection was iteratively selected on the map. For each approach, the appropriate approach direction button on the entry tool was clicked, and a volume appeared in the associated textbox. A travel direction was also indicated for the approach. The process was repeated for each approach. The data were placed into the intersection database and the tool was used to progress to the next intersection by increasing the intersection number by one. This entire process was repeated for each intersection.

Intersection site visit data input

Using the intersection site visit input dialog, intersections were accessed and data entered. First, using the intersection identifier, each location was selected. Then, data related to travel direction, intersection class, control type, control direction, geometry, major road speed limit, minor road speed limit, land use, topography, and surface type were entered. Finally, the data were applied to the database. This was repeated for each intersection.

Crash data collection

After volumes and other site characteristics were entered, the script written to acquire intersection-related crash data was run. This script accessed the Iowa crash database and, using the intersection crash node number, acquired crash frequencies and other data for all crashes in the indicated year(s) that were related to the intersection.

"After" site data collection

"After" site data were collected after some time (e.g., 1 year) had passed. The sites targeted were those that had been altered. The after site data were aggregated, crash and volume data were acquired, and the data were entered.

Data Verification and Exploration

After the data were entered, the accuracy of the data was verified. Verification methods range from development of simple frequency statistics to locating data anomalies to site-by-site examination of entered data. As the second option is tedious, the first method was adopted in this research. The second option was used to investigate anomalies indicated by the first. During data verification, some sites were removed due to inadequate frequencies of that site type or features inapplicable to the model. These two removal criteria resulted from the randomized data collection undertaken. Finalization of the data verification process leads to development of exploratory statistics.

Development of exploratory statistics is standard practice for statisticians. These statistics provide insight into data consistency, both within and between variables. Standard exploratory statistical tools employed include frequencies, scatterplots, histograms, and correlations. Using these, determination of adequate site characteristic frequency can be made. Correlations within and between variables may be identified, perhaps resulting in merging or removal of some variables. Some basic statistical analyses, available within standard statistical software packages, can also be used to obtain further information about proposed models.

Single variable frequencies indicate the number of occurrences of individual variable values. If any values are underrepresented (i.e., too few sites exhibit the value), additional data may be collected or like values combined. Time and resource constraints are relevant and decisions are based on suitability of data combinations. If neither option fits, the site may be discarded from the dataset. If the data are important, the underrepresentation may be ignored until interpretation of results. Frequencies were developed for all dependent, independent, and covariate variables. These frequencies are charted, as shown in Figure 5.6.

Cross-variable frequencies provided information regarding variable interaction. For each value of a grouping variable (e.g., a covariate variable), site frequencies were developed by counting instances of each categorization of another variable (e.g., crashes) for all sites. A histogram was developed, as shown in Figure 5.7. Histograms were developed for all variable pairs. These non-normalized histograms indicate whether individual variable values have inconsistent or unexpected frequencies of

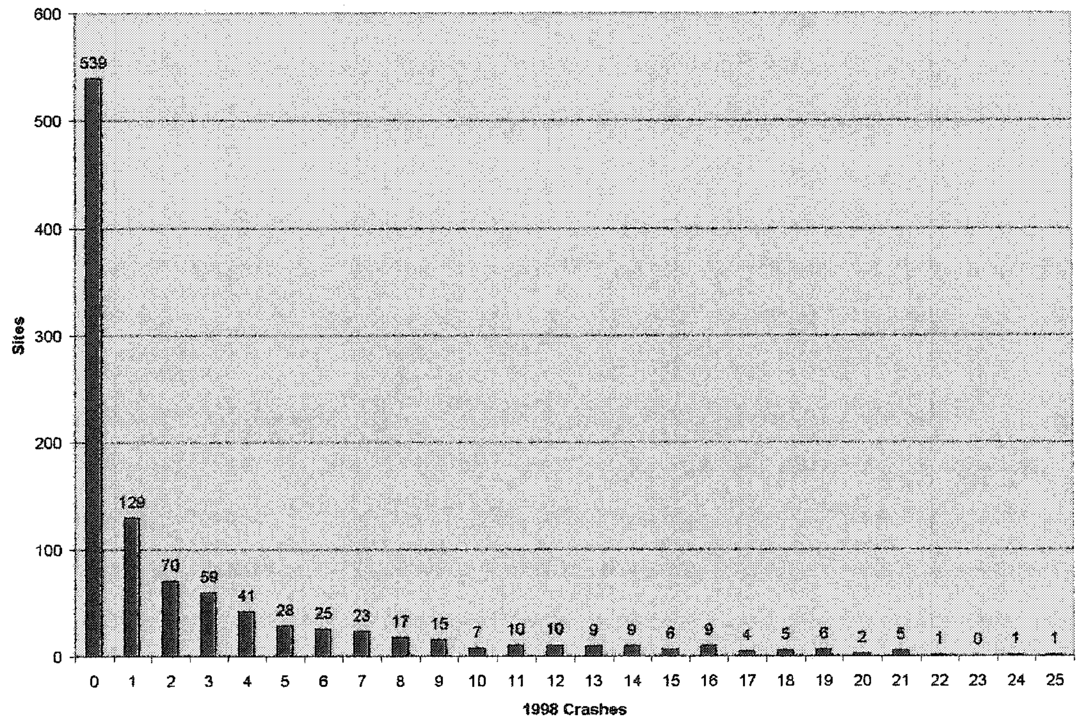


Figure 5.6. Single variable frequency histogram—crashes

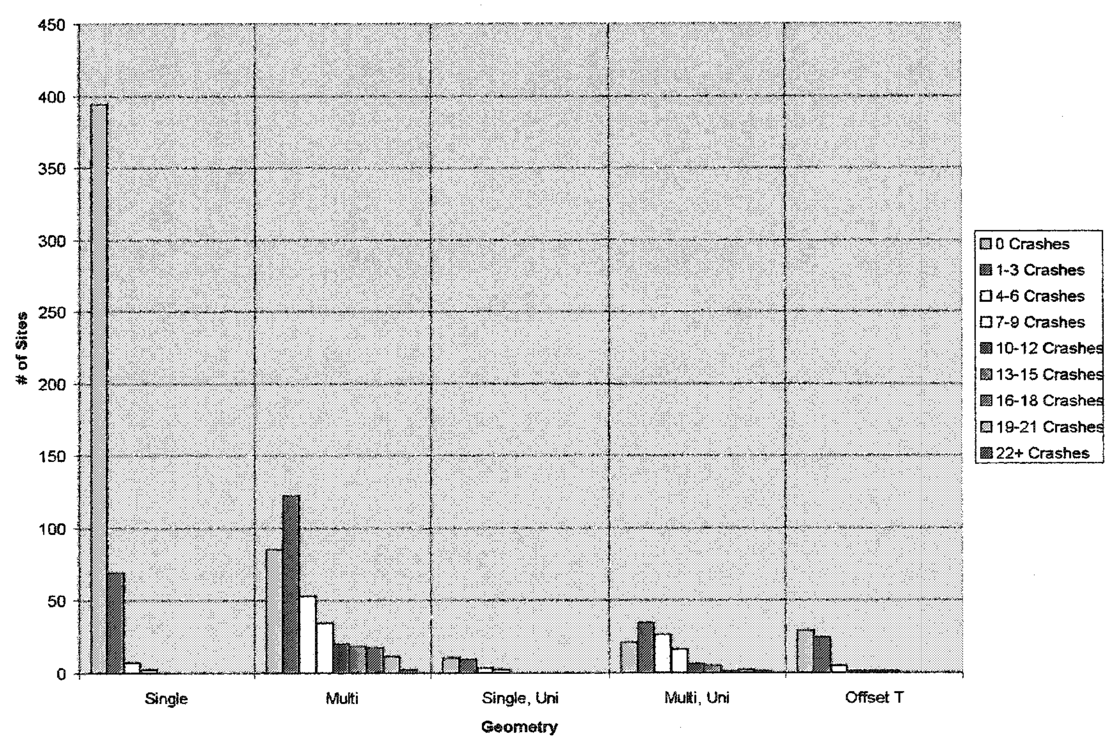


Figure 5.7. Cross-variable frequencies—non-normalized

each categorization of the other variable. For example, in Figure 5.7, few single-lane geometry sites have high crash frequencies. Also, single-lane sites with a one-way roadway have very few sites. Neither of these results is unexpected, as the former are most likely residential streets and the latter are not very frequent.

A related histogram, normalized by total intersections fitting each grouping variable, was developed for each variable, as shown in Figure 5.8. The normalized histograms express the

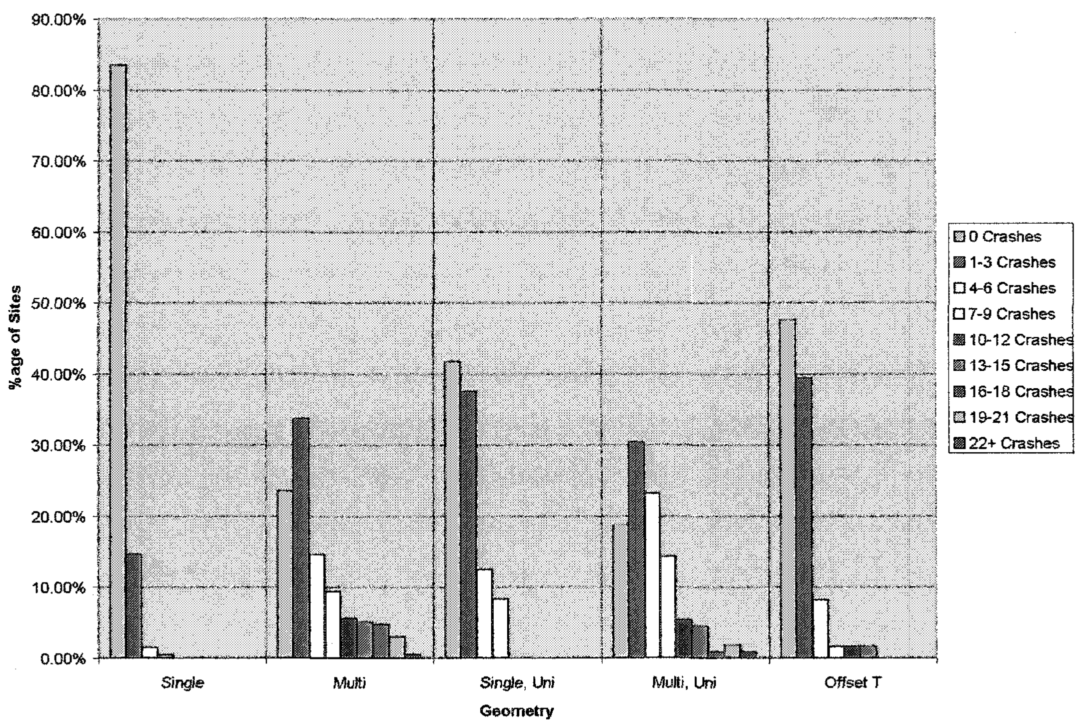


Figure 5.8. Cross-variable frequencies—normalized

frequencies as percentages of sites within each variable value, showing whether particular values of the grouping variable have unexpected frequencies of sites within the grouping variable value.

The non-normalized histograms display the shape of the distribution for each value related to the categorization variable. In Figure 5.7, each of the values has more occurrences of low crash frequency intersections and fewer instances of high crash frequency intersections. Thus, the distributions can be said to be consistent across values. The normalized histograms display percentage of sites within each value fitting each categorization variable. In Figure 5.8, the percentage of low frequency sites is higher within all classes. Both types of histograms were used to assess consistency between values of the grouping variable. If variable value combinations were required (e.g., by software limitations), these histograms were used to determine combinations.

Cross-tabulations for each pair of variables were also constructed. Cross-tabulations display frequencies of each variable level categorized by the elements of the paired variable. Cross-tabulations are related to cross-variable frequency charts, providing information that might indicate insufficient data for certain pairings.

Scatterplots provide information about both the spread of data and indication of relationships between variables, particularly possible correlations. An example scatterplot is shown in Figure 5.9.

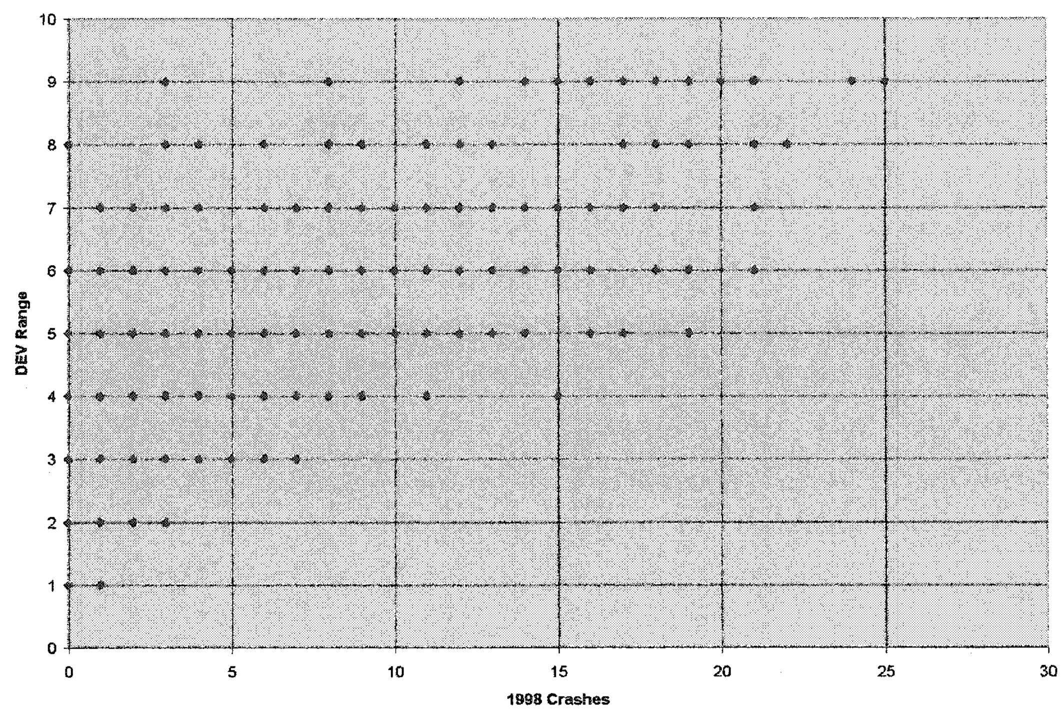


Figure 5.9. Scatterplot—volume vs. crashes

A positive correlation between crashes and volume is discernable for this data set. Potential outliers can also be indicated. Scatterplots are typically generated for each response variable paired with each independent variable or covariate.

Other statistical measures can be generated. Standard statistical measures include means, medians, modes, standard deviations, and correlations. These measures, along with model fit, can be estimated using standard statistical procedures. For example, within SAS Institute's Statistical Analysis Software (SAS) PROC GENMOD fits generalized linear models, which are "an extension of traditional linear models that allow the mean of a population to depend on a linear predictor through a nonlinear link function and allow the response probability distribution to be any member of an exponential family of distributions" (SAS Institute 1999). The base model for this research is a generalized linear model.

PROC GENMOD can be used to provide an expectation of results for subsequent Bayesian analysis (see Appendix H). Using PROC GENMOD, slight model variations can be examined to determine validity prior to further development within less familiar software (e.g., Bayes Using Gibbs Sampling [BUGS]). The model can be adjusted based on PROC GENMOD output, which includes goodness-of-fit criteria, means, standard deviations, covariance and correlation matrices, confidence limits, and measures of variable significance. In addition, PROC GENMOD generates internal dummy variables, with means, standard deviations, and measures of significance output for each. The dummy variable output can be compared with BUGS output to assess BUGS model validity. These internal dummy variables themselves are not output; thus for BUGS operations the dummy variables must be re-developed.

Based on exploratory statistics, the data may be further aggregated. At this point, an iterative process is initiated, progressing from data verification to exploratory statistics. The process can be completed within a few iterations unless data issues are severe.

Dummy Variable Generation and Interpretation

Once the data verification and exploration process was completed, dummy variables were generated for each qualitative explanatory variable. Dummy variables were generated prior to insertion of data into BUGS because BUGS does not generate dummy variables itself.

Dummy variables are essentially an alternative method of representing data using individual binary (e.g., taking on values of 0 or 1) variables for each level of each covariate. For example, given a variable with $p = 4$ levels equal to A, B, C, and D, $p - 1$ dummy variables are required: d_1, d_2, and d_3. Since $d_1 = d_2 = d_3 = 0$ indicates $d_4 = 1$, $p - 1$ dummy variables are sufficient.

Assignment of dummy variable values began with choosing the base or reference level. This value did not have a dummy variable value while the other values did. When the covariate equaled the value for each dummy variable, that dummy variable was assigned a value of 1; otherwise it was assigned a value of 0. Using the example, and assuming level D was the base value, levels A, B, and C were assigned dummy variables d_1, d_2, and d_3, respectively. For value assignment,

- If the covariate has value A, $d_1 = 1$ and, if not, $d_1 = 0$,

- If the covariate has value B, $d_2 = 1$ and, if not, $d_2 = 0$, and
- If the covariate has value C, $d_3 = 1$ and, if not, $d_3 = 0$.

Finally, level D is implied by $d_1 = d_2 = d_3 = 0$.

Interpretation of dummy variables is straightforward and depends on the dummy variable assignment schema chosen. That is, all dummy variable interpretation stems from the choice of the base value and subsequent calculations and interpretations are based on this choice. Using the example, suppose the model is $\mathbf{y}_i = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\mathbf{d}_{1i} + \boldsymbol{\beta}_2\mathbf{d}_{2i} + \boldsymbol{\beta}_3\mathbf{d}_{3i} + \varepsilon$. $\boldsymbol{\beta}\hat{}_1$ is the estimated value for $\boldsymbol{\beta}_1$ and it represents the difference in $\mathbf{y}_i$ when the covariate level changes from D to A or is A rather than the default value of D. $\boldsymbol{\beta}\hat{}_2$ and $\boldsymbol{\beta}\hat{}_3$ have similar interpretations, but for D to B and D to C, respectively.

To obtain similar interpretations for changes between non-D levels, further calculations were required. For example, using the same model, to obtain the difference in $\mathbf{y}_i$ when the covariate level changed from B to A, $\boldsymbol{\beta}\hat{}_2$ was subtracted from $\boldsymbol{\beta}\hat{}_1$ (i.e., $\boldsymbol{\beta}\hat{}_1 - \boldsymbol{\beta}\hat{}_2$). Mathematically, this can be shown as follows:

$$\boldsymbol{\beta}_1 = A - D$$
$$\boldsymbol{\beta}_2 = B - D$$

$$\begin{aligned}\Delta \mathbf{y}_{B \rightarrow A} &= \boldsymbol{\beta}_1 - \boldsymbol{\beta}_2 \\ &= (A - D) - (B - D) \\ &= A - B.\end{aligned}$$

Development of dummy variables is a simple process that can be automated using any code language available. For the purposes of this research, SAS was used to generate the dummy variables for each covariate and save them to text files, which were then inserted into the BUGS script for the model (see Appendix H). The dummy variables were exported to a single file containing columns for each dummy variable as well as identifying intersection information (e.g., ID, north-south street name, east-west street name).

BUGS-based Model Development

To generate samples from the model constructed in previous steps, a method to generate the Markov Chain using Gibbs sampling had to be devised. Because Markov Chain generation for this purpose is not trivial, a group of statisticians have developed software that simplifies the process.

Bayes Using Gibbs Sampling (BUGS) software is freely available via the Internet, the only requirements being registration and declaration of your intended use. A windows version of BUGS, called WinBUGS, is available and was used for this research. The software may be downloaded, and after an email containing the software key is received, BUGS can be used. Manuals and examples are available on the BUGS site as well as through the "Help" menu within BUGS.

Using BUGS notation, the model was constructed within BUGS. BUGS notation is simple but somewhat obscure, requiring an amount of experimentation to represent the model properly. The model construction portion of BUGS script development includes declaration of all models, model relationships, and initial distributions for covariate parameters. BUGS model declarations can include some standard code operations such as loops to iterate through arrays. Data were then inserted into the BUGS script. Finally, initial values for covariate parameters were inserted into BUGS. Initial values for each $\boldsymbol{\beta}$ are required for each Markov Chain–Monte Carlo method chain generated. To develop these initial values, any random number generator can be used to produce sufficient values. Use of code can expedite this, and SAS has functionality for random number generation (see Appendix H).

Run BUGS

BUGS can be run to generate a sufficient number of draws for subsequent analyses. The term "sufficient" refers to a large enough sample to achieve convergence of the Markov chains to their stationary distribution. The term "draws" refers to the samples generated by BUGS for each parameter $\boldsymbol{\beta}$ that are used in further analyses. The draws of each parameter $\boldsymbol{\beta}$ are then used for inference using Monte Carlo methods.

Before performing a full-scale BUGS run, an exploratory run is advisable. This exploratory run is a less time-intensive model run that helps assess model convergence (i.e., test the model) and determine required "burn-in" and possible thinning (i.e., Gibbs chain sampling). Typically, the exploratory run uses a single chain, zeros for all $\boldsymbol{\beta}$ initial values, and a higher number of iterations. The BUGS sample inference tools provide significant indicators for further model runs. If the model does not run or convergence is not achieved, adjustments to the model are required. If model convergence is achieved, the BUGS indicators are used to obtain values for "burn-in" and thinning for the full-scale BUGS run, which will be much more time-intensive. The steps followed for the exploratory BUGS run are explained in Appendix J.

The full-scale BUGS run follows the exploratory run and the updates to the model resulting from this exploration. Given the "burn-in" and thinning values determined from the exploratory run, the full-scale BUGS run involves multiple chains, random numbers for **β** initial values, and sufficient iterations for sample development. Each of the multiple chains has a different initial value, as developed using a random number generator; these different initial values help ensure randomness and also ensure that the chains are independently generated. The steps followed for the final BUGS run are explained in Appendix J. This appendix also details some additional inferential statistics output by BUGS and displays multi-chain output from previously detailed statistics.

Examine BUGS statistics

The BUGS software provides several inferential statistics on the samples drawn via the Gibbs chains. Examination of the BUGS inferential statistics provided exploratory indications of model fit, model convergence, individual variable significance, and individual variable independence.

These inferential statistics are available under the Inference menu within BUGS, under the "Samples…" choice. Choosing "Samples…" opens the sample monitor tool, which requires input of the **β**'s to be monitored. From this dialog, once the model has been run, the inferential statistics can be obtained, including summary statistics (e.g., mean, standard deviation, confidence limit), density diagrams, times series history and trace, quantiles, autocorrelations, and a Gelman-Rubin statistic to assess convergence, which is analogous to an R^2 value and only provides results for multiple chain runs. Each of these inferential statistics is given for each individual **β**, within a single window. They may also be written to ".odc" files for later examination. The graphs, charts, and data values may be saved to image files and text files, using Windows print screen and copy/paste utilities. These inferential statistics are discussed in more detail in Appendix J under the "Model Assessment" subsections.

Develop hierarchical Bayes results

Selecting the "coda" choice from the sample monitor tool within BUGS output individual draw values from each chain for each **β** and a "coda index" that indicates which "coda" list ranges contain each **β**'s draws. For example, a "coda index" range of 1 to 625 for beta0 indicates that the beta0 BUGS draws can be found in rows 1 through 625 in the "coda" list. "Coda" and "coda index" are BUGS terms.

Selecting the "coda" choice generated a "coda chain" for each chain run within BUGS (e.g., 4 "coda chains" for 4 chains). Each "coda chain" was highlighted, copied, and pasted to a text editor (e.g., TextPad) or a spreadsheet (e.g., Microsoft Excel). Within either of these, the "coda" were arranged into a column for each $\boldsymbol{\beta}$, with appropriate column names. Saving these in a file format that SAS can import (e.g., dBASE) allowed future data manipulations using SAS.

Assuming each "coda chain" table and the original dummy variable database were both in a SAS-importable format, SAS code written to import, combine, perform calculations, and export results was run. This SAS code is given in Appendix H. The desired output data from this SAS code were crash frequency and crash rate draws from each value of $\boldsymbol{\beta}$ for each intersection.

Development of frequency and rate databases using SAS

The SAS code imported the original dummy variable database into a SAS data set and modified this data set to contain only the dummy variables. This portion of the SAS code created an intersection data table with number of rows equal to the number of intersections in the database (e.g., 1031) and number of columns equal to the number of covariates ($\mathbf{x}$'s) (e.g., 22 intersection characteristics) in the model (e.g., a table with 1031 rows and 22 columns).

Next, the SAS code imported each "coda chain" table into individual SAS data sets and combined them into a single SAS data set. The SAS code then removed the BUGS draw indication and retained only the $\boldsymbol{\beta}$ columns for each draw output from BUGS. This portion of the code created a $\boldsymbol{\beta}$ table with number of rows equal to the number of draws and number of columns equal to the number of $\boldsymbol{\beta}$'s (one for the intercept and one for each covariate) in the model (e.g., a table with 2500 rows and 22 columns).

The SAS code next used a SAS module called Interactive Matrix Language (IML) to estimate the posterior crash frequency and crash rate values given each draw (e.g., given each possible value of the vector of model parameters). Four separate IML processes were developed to represent distinct steps in the manipulation of matrices. Each of these four IML processes could have been combined into a single process but were kept separate for ease of implementation and monitoring of process results.

Each of the four IML processes performed a portion of the calculations to compute the posterior distributions for the crash frequency and crash rate. From the developed model,

$$\log \boldsymbol{\lambda}_i = \log \mathbf{v}_i + \boldsymbol{\beta}_1\mathbf{x}_{1i} + \boldsymbol{\beta}_2\mathbf{x}_{2i} + \boldsymbol{\beta}_3\mathbf{x}_{3i} + \boldsymbol{\beta}_4\mathbf{x}_{4i} + \boldsymbol{\beta}_5\mathbf{x}_{5i} + \boldsymbol{\beta}_6\mathbf{x}_{6i} + \boldsymbol{\beta}_7\mathbf{x}_{7i} + \boldsymbol{\beta}_8\mathbf{x}_{8i} + \boldsymbol{\beta}_9\mathbf{x}_{9i} + \boldsymbol{\beta}_{10}\mathbf{x}_{10i} + \boldsymbol{\beta}_{11}\mathbf{x}_{11i} + \boldsymbol{\beta}_{12}\mathbf{x}_{12i} + \boldsymbol{\beta}_{13}\mathbf{x}_{13i} + \boldsymbol{\beta}_{14}\mathbf{x}_{14i} + \boldsymbol{\beta}_{15}\mathbf{x}_{15i} + \boldsymbol{\beta}_{16}\mathbf{x}_{16i} + \boldsymbol{\beta}_{17}\mathbf{x}_{17i} + \boldsymbol{\beta}_{18}\mathbf{x}_{18i} + \boldsymbol{\beta}_{19}\mathbf{x}_{19i} + \boldsymbol{\beta}_{20}\mathbf{x}_{20i} + \boldsymbol{\beta}_{21}\mathbf{x}_{21i} + \boldsymbol{\beta}_{22}\mathbf{x}_{22i}.$$

The posterior distribution of the log crash rate ($\log \boldsymbol{\lambda}_i$) was calculated for each of the intersections. From this, the posterior distribution of crash rate ($\log \boldsymbol{\lambda}_i$) was calculated from

$\lambda_I^m = \exp(\log(\lambda_I^m))$,

where m = 1, …, 2500 denotes the draw number. From this, the crash frequency for each draw was calculated and results were generated.

At this point, two separate final result databases existed, containing, for each intersection, draws of crash frequency ($\mathbf{y}_i$) and crash rate ($\boldsymbol{\lambda}_i$). From each intersection's $\mathbf{y}_i$ and $\boldsymbol{\lambda}_i$ values, a variety of additional analyses were developed, including expected values, covariate effects, rankings, and predictions. In addition, an exploratory study of the BUGS results was developed to analyze the assumption of independent and identically distributed (i.i.d.) draws from the four chains and to examine the number of draws required.

Expected values

Expected values for each site were developed directly from the $\tilde{\mathbf{y}}_i$ and $\boldsymbol{\lambda}_i$ values. These $\tilde{\mathbf{y}}_i$ and $\boldsymbol{\lambda}_i$ values represent draws from the posterior distribution (i.e., the distribution resulting from the Bayesian analysis) for each site. For each site, posterior distributions for both the crash frequency, $p(\boldsymbol{\lambda}_i\mathbf{v}_i|\mathbf{y}_i,\underline{\mathbf{x}}_i)$, and the crash rate, $p(\boldsymbol{\lambda}_i|\mathbf{y}_i,\mathbf{v}_i,\underline{\mathbf{x}}_i)$, were obtained. For groups of like sites, combined distributions can be calculated by combining the data from the like sites.

These posterior distributions represent the number of crashes and the crash rate we would expect at a site or site type given that the volumes and other intersection characteristics remain the same. From these distributions, typical statistical measures such as means and standard deviations were obtained. The means are a point estimate of the $\tilde{\mathbf{y}}_i$ and $\boldsymbol{\lambda}_i$ values and the standard deviations are a measure of uncertainty around that point estimate. Graphs of each site distribution, similar to the density charts output by BUGS, were produced. The graphs were developed using the frequencies of each covariate value from the BUGS draws for each site. These charts graphically display the distribution, mean, and standard deviation for each site or site type.

The posterior distributions, for either crash frequency or rate, are a baseline from which to compare changes in frequency or rate. They can be used to predict future frequencies or rates, monitoring them for change. Especially in the case where some intersection characteristics have been updated (e.g., geometric changes, increased enforcement, improved signing, new business), the posterior distributions aid in evaluation of the effectiveness of those changes.

The posterior distributions indicate whether sites of a particular type are significantly different than expected for the site type. The sites that perform better than expected are not as much of a safety concern, but they might be assessed to determine improvements that could be considered for lower performing sites.

Finally, the expected value for each site can be directly compared to assess the magnitudes of difference between sites. Using this information, cutoff points for further consideration might be established or categorizations or tiers of sites could be established.

To develop expected value results from the Bayesian analysis output, additional ArcView Avenue scripts were coded (see Appendix G). These scripts calculate means, standard deviations, variances, maximums, and minimums for both frequency and rate at each site. The output files from the ArcView Avenue scripts were then brought into Excel to produce a column containing the difference between the model output and actual occurrence for each site. An absolute value of the differences for each site was also calculated and totaled to assess absolute difference across sites. This process could easily be applied to particular covariates within the data.

To create individual site densities for crash frequency and rate, another set of ArcView Avenue scripts were coded (see Appendix G). These scripts summarize the frequency and rate values for each site, creating a count for each value. These counts were then brought into Excel and density charts developed for individual sites or for multiple sites.

Covariate effects

The effect of covariates on either crash rates or crash frequencies can be assessed from the posterior distributions of the model parameters $p(\boldsymbol{\beta}_j|\mathbf{y}_i,\mathbf{x}_i)$. Assessment of covariate effects can be done either individually or in combination. That is, a change to either a single covariate or multiple covariates simultaneously could be examined for changes in expected crash frequency or rate.

To examine the effect of single covariates, the posterior distribution of the association between the covariate, $\mathbf{x}_j$, and the crash frequency or crash rate for the site, $p(\boldsymbol{\beta}_j|\mathbf{y}_i,\underline{\mathbf{x}}_i)$, was obtained. For example, consider the case where $\mathbf{x}_j = 1$ if the site is signalized and 0 if it is not, and suppose that $p(\boldsymbol{\beta}_j|\mathbf{y}_i,\mathbf{x}_i)$ is as illustrated in Figure 5.10, everything else being equal; signalization reduces crash

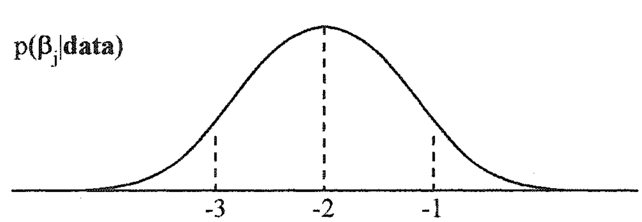


Figure 5.10. Covariate effects—individual

frequency between one and three crashes with a large probability (e.g., 100% here) relative to non-signalized sites. If the distribution contained 0, the probability that crash frequency differs for intersections with and without signalization would be less than 100%, with the amount of distribution on either side of 0 indicating the chance of increase or decrease. The distribution indicates the relative strength of the reduction probability; thus a reduction of two crashes is most likely.

Restated, posterior distributions $p(\boldsymbol{\beta}_j|\mathbf{y}_i,\mathbf{x}_i)$ permit assessing the effects of the various covariates by measuring the increase or decrease in crash frequency or crash rate as altered by one particular intersection alteration (e.g., switching from two-way stop control to four-way stop control, adding a left-turn bay). The information gained helps engineers decide which countermeasure might best be applied given certain intersection characteristics or pick those most likely to benefit safety. Cost-effectiveness must be kept in mind when doing this. Knowledge of inadvisable or less beneficial updates, from a safety viewpoint, would also be available. The concerns of safety could then be more effectively weighed against other concerns (e.g., increased progression/decreased delay).

For multiple covariate analysis, the posterior distribution of these covariates in combination, $p(\boldsymbol{\beta}_j,\boldsymbol{\beta}_k|$ **data**$)$, is obtained. For example, given that $\mathbf{x}_j = 1$ if the site is signalized and 0 if it is not and $\mathbf{x}_k = 1$ if the site has a left turn lane and 0 if it does not, then $p(\boldsymbol{\beta}_j,\boldsymbol{\beta}_k|$ **data**$)$, as illustrated in Figure 5.11, indicates that everything else being equal, the combination of signalization and a left turn lane

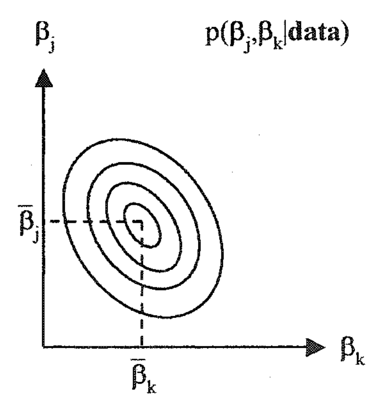


Figure 5.11. Covariate effects—multiple

affects crash frequency somewhere within the probability range indicated with a large probability. This effect is in comparison to sites without those features.

Restated, using this posterior distribution we can assess the effect of factors in combination, measuring the increase or decrease in crash frequency or crash rate when multiple intersection alterations have been made (e.g., switching from stop control to signalization with the addition of left-turn bays). Similar to the one factor example above, an engineer gains knowledge that allows assessment of several alternatives from a safety viewpoint.

If, for example, signalization is associated with the β_j (vertical) scale and presence of a left turn lane is paired with the β_k (horizontal) scale, then the graph of $p(\beta_j,\beta_k \mid \mathbf{data})$ displays both the individual effects and the multiple effects simultaneously. If the outer limit of the concentric ellipses has a range from 1 to 3 on the β_j (vertical) scale and a range from –4 to –2 on the β_k (horizontal) scale, then the combination of signalization and presence of left turn lanes is some combination of these effects. This combined effect is indicated by the intersection of $\beta_{j\ bar}$ and $\beta_{k\ bar}$. Ideally, all pairings are investigated. Pragmatically, only relevant or interesting pairings are examined.

The graph displays the correlation between the effects graphed. In this case, as the probability distribution seems to have a negative slope, the correlation is negative with the degree being relatively severe. One would not, therefore, want to pair these two effects.

Finally, because the example above did not have the distribution crossing 0 for either effect, we can say the individual effects have 100% probability to increase or decrease, as stated. If, however, the distribution crossed 0 for either effect, then that effect would have a chance of being reversed, with the probability of reversal indicated by the amount the distribution was on either side of 0.

Covariate effects were indicated on an aggregate scale by the distribution of crash frequency and crash rate developed for groups. Using densities developed from these distributions, quick assessments of the effects of various covariates were approximated.

To assess individual site covariate effects on a theoretical basis, intersection site characteristic covariates (e.g., geometry, controls) in the data can be altered either singly or in combination. These alterations were done on individual sites, the site crash frequencies and rates were recalculated, and the new values were compared with the original values for the site. Gains or losses at individual sites were then assessed. This can also be done across all sites, with similar sites grouped to aid in assessment. To apply this beyond theory, actual intersection changes would have to be recorded and the value changes compared to crash history after implementation. This was also done.

Rankings

Rankings for each intersection were determined by ordering estimates (e.g., means) of the $\tilde{y}_i$ and λ_i values for each intersection. The $\tilde{y}_i$ and λ_i values were obtained as detailed under the previous section titled “Expected values”.

Sites were ranked according to crash frequency by ordering sites according to $E(y^*|y_i, v_i, \underline{x}_i)$. Sites were ranked with respect to crash rate by ordering sites according to $E(y^*/v_i|y_i, \underline{x}_i)$. To calculate these estimates of crash frequency and rate for each site, along with a probability of each site's ranking value, each site was ranked for all draws individually and a frequency of rank values was retained for each site. To rank the sites on each draw, SAS code was added to that written for development of hierarchical Bayes results in Appendix H. The process is illustrated in Table 5.1. A percentage was

Table 5.1. Site rankings per draw

	Rank											
Draw	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**...**	**1031**
1	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1031}
2	y_1	y_4	y_5	y_6	y_2	y_3	y_9	y_8	y_7	y_{10}	...	y_{1001}
3	y_1	y_5	y_3	y_4	y_2	y_9	y_8	y_6	y_7	y_{10}	...	y_{954}
4	y_5	y_1	y_3	y_4	y_6	y_9	y_2	y_8	y_7	y_{10}	...	y_{1025}
5	y_1	y_4	y_5	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1031}
6	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1031}
7	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1031}
8	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{954}
9	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1007}
10	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1031}
...	...	...	...	...	...	...	...	...	...	...	...	...
2500	y_1	y_5	y_4	y_3	y_2	y_6	y_9	y_8	y_7	y_{10}	...	y_{1023}

derived from the rankings for each site from each of the draws, as shown in Table 5.2. These percentages represent the frequency of each site's rankings throughout the draws. For example, site 1 is ranked first 80% of the time, second 15%, third 3%, and so on. A weighted site ranking could be developed from these percentages.

A distribution of ranking for each site is also derivable. This distribution, when graphically represented, allows quick visual inspection of ranks, as shown in Figure 5.12. From the graph, it is

Table 5.2. Site ranking percentages—tabular

	Rank											
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**...**	**1031**
1	80%	15%	3%	1%	1%	0%	0%	0%	0%	0%	...	0%
2	10%	75%	8%	4%	2%	1%	0%	0%	0%	0%	...	0%
3	5%	6%	35%	35%	9%	4%	3%	2%	1%	0%	...	0%
4	1%	2%	40%	25%	18%	9%	3%	2%	0%	0%	...	0%
5	1%	1%	13%	15%	40%	20%	7%	1%	1%	1%	...	0%
6	1%	1%	1%	18%	20%	25%	23%	9%	1%	1%	...	0%
7	1%	0%	0%	1%	2%	5%	15%	16%	22%	35%	...	0%
8	1%	0%	0%	1%	7%	35%	35%	13%	5%	3%	...	0%
9	0%	0%	0%	0%	1%	1%	10%	8%	7%	45%	...	0%
10	0%	0%	0%	0%	0%	0%	3%	3%	4%	15%	...	0%
...	...	...	...	...	...	...	...	...	...	...	...	...
1031	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	...	95%

apparent that sites 1 and 2 are clearly ranked first and second, with site 1 being more likely ranked first and site 2 being more likely ranked second. After these two sites, the picture becomes less clear. Sites 3 and 4, for example, are probably ranked third and fourth, but discerning which is more difficult. Though site 4 has been ranked third a higher percentage of the time when compared to site 3, the distribution of rankings for site 3 is tighter than the distribution of rankings for site 4. Thus, these is more uncertainty about the relative rank of site 4. The same follows for the other sites, though there seems to be a break at the eighth ranking, which might suggest that sites 3, 4, 5, 6, and 8 are somewhat worse than sites 7, 9, and 10. A graph with all ranking distributions could be constructed but that might be quite difficult to interpret. Instead, distributions of the rankings for each site were constructed, with means, standard deviations, and other statistical measures calculated.

The end result is a distribution of ranking values for both crash frequency and crash rate for each site. These distributions not only provide a ranking but also an indication of the relative probability

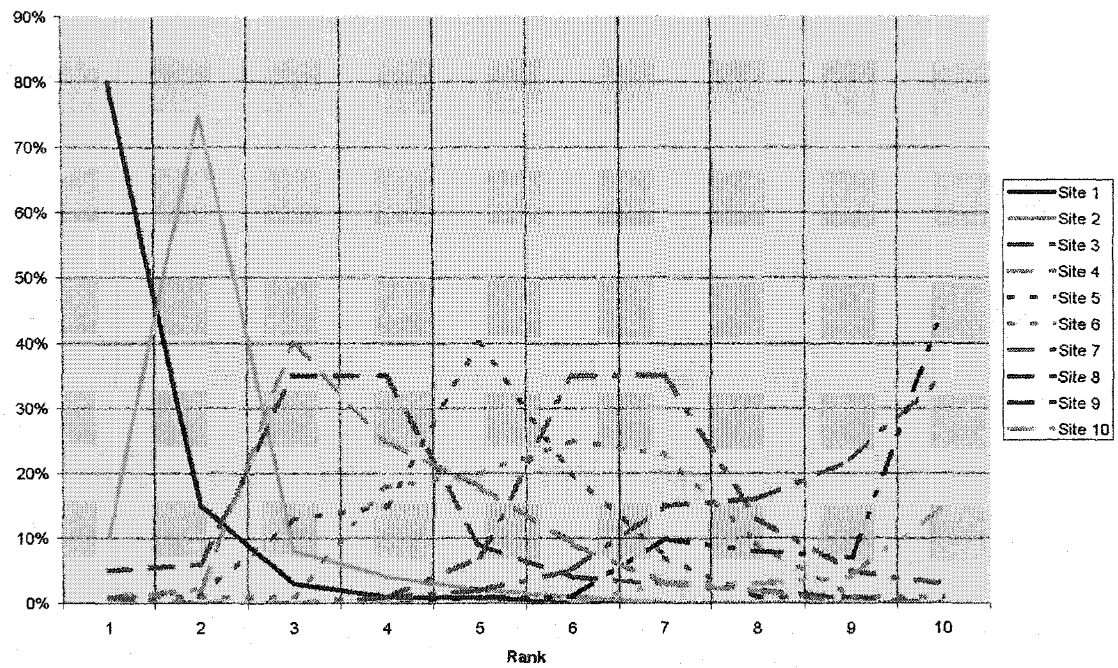


Figure 5.12. Site ranking percentages—graph

of each site's ranking. A combination ranking, similar to Iowa's current ranking methodology (Appendix A), is also possible.

To assess changes to the rankings if site alterations were made, rankings of expected crash frequencies or crash rates, post-alteration, were constructed. To do this, we used the mean of the posterior predictive distribution, $E\{y^*_i|y_i,v_i,x_2.,x_p\}$. This value represents the mean of the posterior predictive distribution for the crash frequency for each intersection given the observed number of crashes at the intersection, its traffic volume, and its characteristics x_2., x_p.

To rank the intersections in terms of crash frequencies, the posterior predictive distribution of the crashes were used to compute, for each intersection, a mean, $E\{y^*_i|y_i,v_i,x_2.,x_p\}$. The sites could then be ranked based on these mean crash frequencies.

To rank the intersections using crash rates, the posterior predictive distribution of the crash rate was used to compute, for each intersection, a mean, $E\{y^*_i/v_i|y_i,x_2.,x_p\}$. The sites could then be ranked according to these mean crash rates.

To predict the influence of an improvement, the change in ranking of a site can be used as one metric. If the ranking of a particular site increases (i.e., is less near the top) significantly, then the assumption would be that the improvement had a positive effect on the overall safety of the site. Further analysis of the exact effect would be needed, however.

Data collected on selected intersections after improvements were used to develop expected crash frequencies and crash rates for altered sites. All other sites were assumed unaltered. These crash frequencies and crash rates were then used to construct new site rankings, and the rankings were analyzed for the altered intersections to assess their relative change.

Predictions

Predictions of future crash frequencies and crash rates for each intersection can be determined by first calculating the posterior predictive distribution for each site, $p(\tilde{y}_i|y_i,v_i,\underline{x}_i)$, where $p(\tilde{y}_i|y_i,v_i,\underline{x}_i) = \int p(\tilde{y}_i|v_i,\lambda_i,y_i,\underline{x}_i)\, p(\lambda_i|\underline{\boldsymbol{\beta}},v_i,y_i,\underline{x}_i)\, p(\underline{\boldsymbol{\beta}}|v_i,y_i,\underline{x}_i)\, d\lambda_i\, d\underline{\boldsymbol{\beta}}$. The first portion of this, $p(\tilde{y}_i|v_i,\lambda_i,y_i,\underline{x}_i)$, is the likelihood function, meaning that given the volume, crash rate, crash history, and covariates, future crash likelihood is given by this function. The second portion, $p(\lambda_i|\underline{\boldsymbol{\beta}},v_i,y_i,\underline{x}_i)$, represents the posterior distribution of the crash rates (λ_is) given the parameters and the data. The third portion, $p(\underline{\boldsymbol{\beta}}|v_i,y_i,\underline{x}_i)$, represents the posterior distribution of the parameters ($\underline{\boldsymbol{\beta}}$s) given the data. That is, given the data (volume, crash history, and covariates) we can obtain estimates of the parameters.

Taken all together, these portions represent the joint probability distribution of future crashes ($\tilde{y}$), crash rates (λ), and parameters ($\underline{\boldsymbol{\beta}}$) conditional on the data (volume, crash history, and covariates). Integrating over $\underline{\boldsymbol{\beta}}$ then λ_i in succession would result in a posterior predictive distribution. However, integration of this equation is difficult. To obtain $p(\tilde{y}_i|y_i,v_i,\underline{x}_i)$, alternative means such as MCMC methods and, more specifically, Gibbs sampling, must be used. The calculation of $p(\tilde{y}_i|y_i,v_i,\underline{x}_i)$ results in a distribution, as shown in Figure 5.13, and an assessment of $E(\tilde{y}_i|y_i,v_i,\underline{x}_i)$.

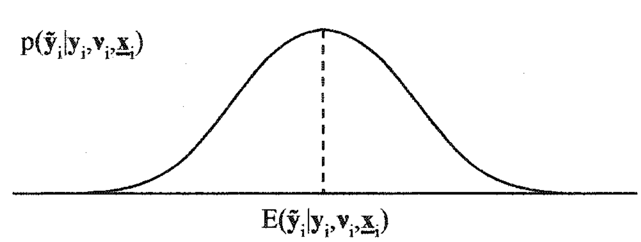


Figure 5.13. Posterior predictive distribution

In general, to get $p(\tilde{y}_i|y_i,v_i,\underline{x}_i)$ given the model, $p(\tilde{y}_i|y_i,v_i,\underline{x}_i) = \int p(\tilde{y}_i|v_i,\lambda_i,y_i,\underline{x}_i)\, p(\lambda_i|\underline{\boldsymbol{\beta}},v_i,y_i,\underline{x}_i)\, p(\underline{\boldsymbol{\beta}}|v_i,y_i,\underline{x}_i)\, d\lambda_i\, d\underline{\boldsymbol{\beta}}$:

1. Draw $\underline{\beta}$ from $p(\underline{\beta}|v_i, y_i, \underline{x}_i)$.
2. Compute $\log(\lambda_i) = \log v_i + \underline{\beta}' \underline{x}_i$.
3. Draw $\tilde{y}_i$ from **Poisson** (λ_i).

Repeat steps 1 through 3 many times, obtaining draws that provide the distribution. Given the distribution of $p(\tilde{y}_i|y_i, v_i, \underline{x}_i)$, future crash frequencies and rates for each intersection can be calculated.

Restated, if consideration of site improvements were underway, a prediction of the crash frequency and the crash rate, given the changes, is possible. For example, if an intersection were being considered for addition of a traffic signal and a left turn lane, the data (**x**'s) for the dummy variables recording this information would change from 0 to 1. Thus, $\underline{x}_i$ would change to $\underline{x}_i^*$, with the indicator variables for signalization and presence of a left turn lane switch from 0 to 1. Now, the interest is in $p(\tilde{y}_i^*|y_i, \underline{x}_i^*)$, the prediction of crash frequency, and $p(\tilde{y}_i^* - \tilde{y}_i \,|y_i, \underline{x}_i, \underline{x}_i^*)$, the anticipated change in crash frequency. Similar equations were developed for crash rate.

Two types of predictions were enabled from Bayesian analysis: prediction of frequency or rate given that nothing changes and prediction of frequency or rate accompanying a change. The first type is a direct application of the results from the expected values, along with the standard deviations and associated probabilities. The second type is an application of the covariate effects.

Exploratory study of BUGS results

To assess the effect of the number of draws, a variety of sample sizes were compared. Number of draws were compared on three levels: 2500, 625, and 50. The 2500 level is the number of draws selected for this research with 625 draws for each chain run in the model. The 50 level is an arbitrarily low value to assess whether the same conclusions could be reached using a much more limited draw. In theory, no significant difference should be noted between these various draw levels other than differences in variance. The scripts noted in the "Expected values" section can be run on subsets of draws, namely the 625 and the 50.

CHAPTER 6. ANALYSIS AND RESULTS

Results stemming from the methodology described in Chapter 5 are detailed in this chapter. Due to the large number of possible results that could be generated from the large variety of covariates in the model, only a subset of possible results is displayed.

Final Model

The model can be summarized in general terms as follows:

$$y_i \mid v_i, \underline{x}_i \sim \textbf{Poisson}(\lambda_i)$$
$$\log(\lambda_i) = \log v_i + \underline{\beta}' \, \underline{x}_i$$
$$\beta_j \sim N(0,1000),$$

for each i^{th} site with variables

y_i = crashes frequency at i^{th} site during study period ≥ 0;

v_i = traffic volume entering i^{th} site during study period (DEV) ≥ 0;

λ_i = crash rate at i^{th} site during study period;

$\underline{x}_i$ = vector of covariates, or site characteristics, for i^{th} site; thus $\underline{x}_i' = [x_{1i}, x_{2i}, \ldots, x_{pi}]$; and

$\underline{\beta}$ = vector of covariate parameters, or slopes; thus $\underline{\beta}' = [\beta_1, \beta_2, \ldots, \beta_p]$.

where p site characteristics are included in the model.

The final model displays each of the covariate variable matrices and their respective β matrices by expanding $\log(\lambda_i) = \log v_i + \underline{\beta}' \, \underline{x}_i$:

$$\log \lambda_i = \log v_i + \beta_{\text{Travel Direction}} * \text{Travel Direction}_i + \beta_{\text{Intersection Class}} * \text{Intersection Class}_i + \beta_{\text{Geometry}} * \text{Geometry}_i + \beta_{\text{Speed Limit 1}} * \text{Speed Limit 1}_i + \beta_{\text{Speed Limit 2}} * \text{Speed Limit 2}_i + \beta_{\text{Topography}} * \text{Topography}_i + \beta_{\text{Land Use}} * \text{Land Use}_i + \beta_{\text{Surface Type}} * \text{Surface Type}_i + \beta_{\text{Controls}} * \text{Controls}_i,$$

where each of the covariates is a vector of dummy variables defining the variable.

Expressed with arrays of dummy variables (as required for BUGS), the model becomes

$$\log \lambda_i = \log v_i + \beta_1 * tdir_i + \beta_2 * iclass_i + \beta_{3\text{-}6} * geo[1{:}4]_i + \beta_7 * splm1_i + \beta_8 * splm2_i + \beta_9 * topo_i + \beta_{10\text{-}15} * landuse[1{:}6]_i + \beta_{16} * stype_i + \beta_{17\text{-}22} * cont[1{:}6]_i.$$

Expansion of the arrays results in the following:

$$\log \lambda_i = \log v_i + \beta_1 * tdir_i + \beta_2 * iclass_i + \beta_3 * geo1_i + \beta_4 * geo2_i + \beta_5 * geo3_i + \beta_6 * geo4_i + \beta_7 * splm1_i + \beta_8 * splm2_i + \beta_9 * topo_i + \beta_{10} * landuse1_i + \beta_{11} * landuse2_i + \beta_{12} * landuse3_i + \beta_{13} * landuse4_i + \beta_{14} * landuse5_i + \beta_{15} * landuse6_i + \beta_{16} * stype_i + \beta_{17} * cont1_i + \beta_{18} * cont2_i + \beta_{19} * cont3_i + \beta_{20} * cont4_i + \beta_{21} * cont5_i + \beta_{22} * cont6_i.$$

Using the dummy variable array expression, the number of levels within each model covariate can be quickly assessed. For example, travel direction, intersection class, topography, and surface type have only two levels because they have no array indicated. Geometry has five levels, land use has seven, and controls has seven. The speed limit covariates are continuous.

Characterization of Collected Data

Initial data collection involved recording of intersection characteristic data (e.g., number of lanes, volumes, pavement) for each approach and crash history data. Approach data were collected for approximately 1100 sites. Many of these were discarded for a variety of reasons including uniqueness (e.g., low frequency of occurrence). 1031 intersections from Ames (221) and Des Moines (810), Iowa, were ultimately included in the model

The approach data were aggregated to intersection values. The data were examined for possible combination, based on knowledge of the variables collected and model requirements. This examination resulted in aggregation values that converted the approach-based data to intersection-based data. For example, if four approaches were recorded, travel direction was set to four-way.

Initial data aggregation was examined using exploratory statistics (i.e., frequency histograms, paired-variable scatterplots, and paired-variable frequency histograms). This exploratory examination, coupled with software constraints, resulted in a final data aggregation. The data field and element definitions for the data, after final data aggregation, are shown in Table 6.1. The speed limit values are in miles per hour (mph), with speed limit 1 equal to speed limit for the street that has a higher speed limit going through an intersection and speed limit 2 equal to the speed limit for the street that has a lower speed limit going through an intersection. The daily entering vehicles and the crash frequency at each site during 1998 were also collected.

Table 6.1. Data after final aggregation

Data field	Element definition
Travel Direction	1 = 4-way and 2 = 3-way
Intersection Class	1 = municipal/municipal and 2 = non-municipal
Intersection Geometry	1 = single-lane entering from each direction 2 = multi-lane 3 = single-lane entering from each direction and a one-way 4 = multi-lanes and a one-way 5 = Offset-T
Speed Limit 1 (mph)	1 = 10, 2 = 15, 3 = 20, 4 = 25, 5 = 30, 6 = 35, 7 = 40, 8 = 45, and 9 = 50
Speed Limit 2 (mph)	1 = 10, 2 = 15, 3 = 20, 4 = 25, 5 = 30, 6 = 35, 7 = 40, 8 = 45, and 9 = 50
Topography	1 = Level and 2 = Rolling
Land Use	1 = Residential/Normal (base case) 2 = Business/Manufacturing 3 = School 4 = Recreational 5 = Hospital 6 = Church/Cemetery 7 = Parking Lot
Surface Type	1 = ACC and 2 = PCC
Controls	0 = Little or no control 1 = 4-way Traffic Signal 2 = 3-way Traffic Signal 3 = 1- or 2- way Signal 4 = 3- or 4-way Stop 5 = 2-way Stop 6 = 1-way Stop

For input into BUGS, dummy variables were developed for each of the variables. The dummy variable definitions (and the BUGS model variables) for the discrete data are shown in Table 6.2. Four variables were continuous (i.e., speed limit 1, speed limit 2, DEV, and 1998 crash frequency).

GENMOD Results

Using the Statistical Analysis Software (SAS) procedure GENMOD, code was developed to generate analysis results for a generalized linear model (GLIM) (i.e., the type of model defined for this research) based on the data. Results generated using GENMOD should provide similar estimates

Table 6.2. Final dummy variables

Data field	Element definition
Travel Direction	tdir = 1 if Travel Direction = 1, 0 otherwise Travel Direction = 2 is implied by tdir = 0
Intersection Class	iclass1 = 1 if Intersection Class = 1, 0 otherwise Intersection Class = 2 is implied by iclass1 = 0
Intersection Geometry	geo1 = 1 if Intersection Geometry = 1, 0 otherwise geo2 = 1 if Intersection Geometry = 2, 0 otherwise geo3 = 1 if Intersection Geometry = 3, 0 otherwise geo4 = 1 if Intersection Geometry = 4, 0 otherwise Intersection Geometry = 5 is implied by geo1, geo2, geo3, and geo4 = 0
Topography	topo = 1 if Topography = 1, 0 otherwise Topography = 2 is implied by topo = 0
Land Use	landuse1 = 1 if Land Use = 2, 0 otherwise landuse2 = 1 if Land Use = 3, 0 otherwise landuse3 = 1 if Land Use = 4, 0 otherwise landuse4 = 1 if Land Use = 5, 0 otherwise landuse5 = 1 if Land Use = 6, 0 otherwise landuse6 = 1 if Land Use = 7, 0 otherwise Land Use = 1 is implied by landuse1, landuse2, landuse3, landuse4, landuse5, and landuse6 = 0
Surface Type	stype = 1 if Surface Type = 1, 0 otherwise Surface Type = 2 is implied by stype = 0
Controls	cont1 = 1 if Controls = 1, 0 otherwise cont2 = 1 if Controls = 2, 0 otherwise cont3 = 1 if Controls = 3, 0 otherwise cont4 = 1 if Controls = 4, 0 otherwise cont5 = 1 if Controls = 5, 0 otherwise cont6 = 1 if Controls = 6, 0 otherwise Controls = 0 is implied by cont1, cont2, cont3, cont4, cont5, and cont6 = 0

for individual βs as Bayesian analysis, providing initial verification of Bayesian results.

Using GENMOD, $\mathbf{y}_i$ is modeled against the collected variables, with the distribution and the offset variable (i.e., natural log of the volume) specified. PROC GENMOD generates its own dummy variables and parameters from this specification. PROC GENMOD produces goodness-of-fit measures, parameter estimates, and statistics that indicate contributions of individual variables. The parameter estimates are used to validate BUGS model output during script development. Means, standard deviations, confidence limits, and significance from both procedures should be similar. If not, the BUGS script must be modified.

Note that GENMOD only provides point estimates of the βs and not samples. Bayesian analysis, by providing samples and subsequent distributions for each site, facilitates the development of results that GENMOD cannot

Goodness-of-fit

Statistics that summarize model fit are shown in Table 6.3. Review of these statistics can help in

Table 6.3. GENMOD—goodness-of-fit

Criterion	DF	Value	Value/DF
Deviance	1007	1690.71	1.68
Scaled deviance	1007	1690.71	1.68
Pearson chi-square	1007	1971.44	1.96
Scaled Pearson X2	1007	1971.44	1.96
Log likelihood		1914.75	

judging model adequacy. Comparing the deviance, 1690.71, with its asymptotic χ^2 with 1007 degrees of freedom distribution, a p-value of zero is obtained. This indicates that the model is adequate for modeling the dependent variable.

Analysis of parameter estimates

Table 6.4 displays several columns containing values for each parameter in the model. The table displays each parameter's name, along with the degrees of freedom associated with that parameter, the estimated value of the parameter, the standard error of this estimate, the confidence intervals, and a Wald χ^2 statistic and its associated p-value for testing the significance of the parameter to the model. The rows that have zeros throughout indicate variables have been found to be linearly dependent with the variables preceding them (e.g., travel direction: 3-way has had all of its variability explained by travel direction: 4-way and thus adds nothing to the model).

From Table 6.4, estimated values were obtained for each parameter for comparison with later Bayesian model results. This aided in verifying the results of the Bayesian model, as the results of these two methods, in this regard, should not differ greatly. The individual p-values were assessed to determine likely significant variables at the 0.05 level. Note that the significant variables have confidence limits that do not encompass 0. Bayesian model results should be similar. The controls variables all had high standard errors and were not significant, indicating possible autocorrelation.

Table 6.4. GENMOD—analysis of parameter estimates

Parameter		DF	Estimate	Standard error	Wald 95% confidence limits		χ^2	Pr > χ^2	Sig.
Intercept		1	-9.430	0.767	-10.93	-7.93	151.19	<0.0001	Y
Travel Direction: 4-way	1	1	0.421	0.114	0.20	0.65	13.56	0.0002	Y
Travel Direction: 3-way	2	0	0	0	0	0	.	.	
Int. Class: municipal	1	1	-0.033	0.049	-0.13	0.06	0.45	0.5027	N
Int. Class: non-municipal	2	0	0	0	0	0	.	.	
Geometry: single-lane	1	1	0.040	0.140	-0.24	0.31	0.08	0.7772	N
Geometry: multi-lane	2	1	0.255	0.111	0.04	0.47	5.26	0.0218	Y
Geometry: single-, one-way	3	1	0.331	0.189	-0.04	0.70	3.05	0.0806	N
Geometry: multi-, one-way	4	1	0.021	0.142	-0.26	0.30	0.02	0.8840	N
Geometry: Offset T	5	0	0	0	0	0	.	.	
Speed Limit: Major/Higher		1	-0.026	0.025	-0.08	0.02	1.12	0.2907	N
Speed Limit: Minor/Lower		1	0.173	0.029	0.12	0.23	35.11	<0.0001	Y
Topography: Level	1	1	-0.289	0.155	-0.59	0.01	3.48	0.0621	N
Topography: Grade	2	0	0	0	0	0	.	.	
Land Use: Residential	1	1	-0.162	0.117	-0.39	0.07	1.93	0.1650	N
Land Use: Business	2	1	0.196	0.092	0.01	0.38	4.5	0.0340	Y
Land Use: School	3	1	0.412	0.108	0.20	0.62	14.53	0.0001	Y
Land Use: Recreational	4	1	0.135	0.130	-0.12	0.39	1.07	0.3007	N
Land Use: Hospital	5	1	-0.057	0.178	-0.41	0.29	0.1	0.7514	N
Land Use: Church/Cemetery	6	1	0.187	0.129	-0.07	0.44	2.11	0.1467	N
Land Use: Parking Lot	7	0	0	0	0	0	.	.	
Surface Type: ACC	1	1	0.112	0.047	0.02	0.20	5.78	0.0162	Y
Surface Type: PCC	2	0	0	0	0	0	.	.	
Controls: None	0	1	-1.405	0.798	-2.97	0.16	3.1	0.0782	N
Controls: 4-way Signal	1	1	0.236	0.718	-1.17	1.64	0.11	0.7418	N
Controls: 3-way Signal	2	1	0.249	0.721	-1.17	1.66	0.12	0.7304	N
Controls: 1-/2-way Signal	3	1	0.318	0.724	-1.11	1.74	0.19	0.6605	N
Controls: 3-/4-way Stop	4	1	-0.148	0.730	-1.58	1.28	0.04	0.8398	N
Controls: 2-way Stop	5	1	-0.386	0.715	-1.79	1.02	0.29	0.5891	N
Controls: 1-way Stop	6	1	-0.846	0.725	-2.27	0.58	1.36	0.2437	N
Controls: Yield	7	0	0	0	0	0	.	.	

Note: The estimate and standard error (grey shaded) are the SAS PROC GENMOD estimates for the β values and the standard deviation, or uncertainty, in the estimates. The bolded variables are those that have been determined to be significant, based on the p-value (Pr > χ^2). The significance is indicated also by the values outlined in red dotted lines (e.g., significance = Y). The values outlined in green are those β values that may be compared with BUGS results and those with orange lines to the left are those that may not be, due to different dummy variable definitions. The values outlined in red indicate high standard errors. The significance values outlined in blue correspond to the non-significant β values with high standard error.

Exploratory BUGS Results

A model script was developed for running the model with BUGS. Changes to the script were made if results did not compare with the GENMOD estimates. The results were evaluated using estimated values of individual covariate β's, indicators of convergence, and model strength.

Using initial values of zero for each β and only one chain per model run, relatively quick assessment of script results were achieved. Several iterations of the script were run, ending when output results compared to the GENMOD results. The final exploratory model script became the final model script after changes to the data and initial β values.

The following tables and figures display the results of the exploratory model, which was run for 30,000 iterations without thinning (e.g., sampling from the iterations). Table 6.5 displays estimated means, standard deviations, errors, and confidence intervals.

The mean values must be interpreted with respect to base level for each variable as per dummy variable requirements. For example, travel direction: four-way was interpreted with respect to travel direction: three-way. Each of the land use variables were interpreted with respect to land use: residential. The means were compared to the GENMOD results. For variables with the same base variables (i.e., variables included by default in the model), the BUGS and GENMOD results matched, indicating proper scripting of the model within BUGS.

The standard deviations for many of the variables were small. Each of the controls dummy variables and the land use: business variables were higher. The results for the controls dummy variables were similar to those from GENMOD. For variables with the same base variables, the BUGS and GENMOD standard deviations were similar.

Confidence intervals for each variable can be assessed similarly to GENMOD. For each variable, if the range encompasses zero, there is less certainty regarding significance. Ranges that do not encompass zero are more certainly significant. The variables judged significant in this fashion via the BUGS results are similar to those indicated by GENMOD.

An additional interpretation is possible using BUGS results. The amount the range encompasses zero indicates probability of increase or decrease in crash frequency due to an incremental change in the variable. For example, because geometry: multi-one-way has about equal amounts on either side of zero, the probability of incremental change in this variable raising or lowering crash frequency is about equal (i.e., 50%). However, for geometry: multi-lane, the probability of the effect can be determined with complete certainty (i.e., 100 percent) because the range does not cross zero.

The density diagrams shown in Figure 6.1 display the table values visually. Similar conclusions can be determined from these diagrams. Densities that cross zero are less significant. By drawing a

Table 6.5. Exploratory model—statistics

Node	Variable	Mean	SD	MC error	Credible set 2.5%	Median	97.5%
β_0	**Intercept**	-11.120	0.493	0.036	**-12.14**	**-11.09**	**-10.25**
β_1	**Travel Direction: 4-way**	0.430	0.118	0.005	**0.19**	**0.43**	**0.66**
β_2	Int. Class: municipal	-0.031	0.048	0.001	-0.13	-0.03	0.06
β_3	Geometry: single-lane	0.047	0.141	0.004	-0.23	0.05	0.32
β_4	**Geometry: multi-lane**	0.266	0.113	0.004	**0.05**	**0.26**	**0.49**
β_5	Geometry: single-, one-way	0.329	0.190	0.004	-0.05	0.33	0.70
β_6	Geometry: multi-, one-way	0.026	0.144	0.004	-0.25	0.03	0.31
β_7	Speed Limit: Major/Higher	-0.025	0.025	0.001	-0.08	-0.02	0.02
β_8	**Speed Limit: Minor/Lower**	0.173	0.029	0.001	**0.11**	**0.17**	**0.23**
β_9	Topography: Level	-0.266	0.154	0.008	-0.56	-0.27	0.06
β_{10}	**Land Use: Business**	0.361	0.079	0.002	**0.21**	**0.36**	**0.52**
β_{11}	**Land Use: School**	0.578	0.096	0.002	**0.39**	**0.58**	**0.76**
β_{12}	**Land Use: Recreational**	0.296	0.122	0.002	**0.05**	**0.30**	**0.53**
β_{13}	Land Use: Hospital	0.099	0.167	0.002	-0.24	0.10	0.42
β_{14}	**Land Use: Church/Cemetery**	0.348	0.120	0.002	**0.11**	**0.35**	**0.58**
β_{15}	Land Use: Parking Lot	0.163	0.116	0.002	-0.07	0.16	0.39
β_{16}	**Surface Type: ACC**	0.115	0.047	0.001	**0.02**	**0.11**	**0.20**
β_{17}	**Controls: 4-way Signal**	1.704	0.487	0.035	**0.84**	**1.66**	**2.78**
β_{18}	**Controls: 3-way Signal**	1.721	0.471	0.034	**0.88**	**1.68**	**2.75**
β_{19}	**Controls: 1-/2-way Signal**	1.791	0.477	0.034	**0.93**	**1.75**	**2.83**
β_{20}	**Controls: 3-/4-way Stop**	1.309	0.496	0.034	**0.41**	**1.27**	**2.37**
β_{21}	**Controls: 2-way Stop**	1.082	0.477	0.034	**0.24**	**1.04**	**2.13**
β_{22}	Controls: 1-way Stop	0.627	0.460	0.033	-0.18	0.58	1.63
β_{23}	Controls: Yield	1.207	0.930	0.034	-0.82	1.27	2.87

Note: The mean and standard deviation (shaded grey) are the Bayes estimates for the β values and the standard deviation, or uncertainty, in the estimates. The bolded variables are those that are not 100% on one side of zero, as indicated by the credible set values. The amount that each β value falls to one side of zero is indicative of the "significance." The values outlined in green are those β values that may be compared with SAS PROC GENMOD results and those with orange lines to the left are those that may not be, due to different dummy variable definitions. The values outlined in red indicate high standard deviations and errors.

vertical line at zero, probabilities can be approximated by estimating the area under the curve on either side. Density diagrams will be discussed more fully with the final model results.

The sample values obtained from the last 200 iterations are shown in Figure 6.2. The trace diagrams help in assessment of model convergence over the most recent iterations, limiting the scale of the variability for more detailed assessment. The trace diagrams are produced for all dummy variables. Being reasonably stable, none of these trace diagrams indicate failure of convergence.

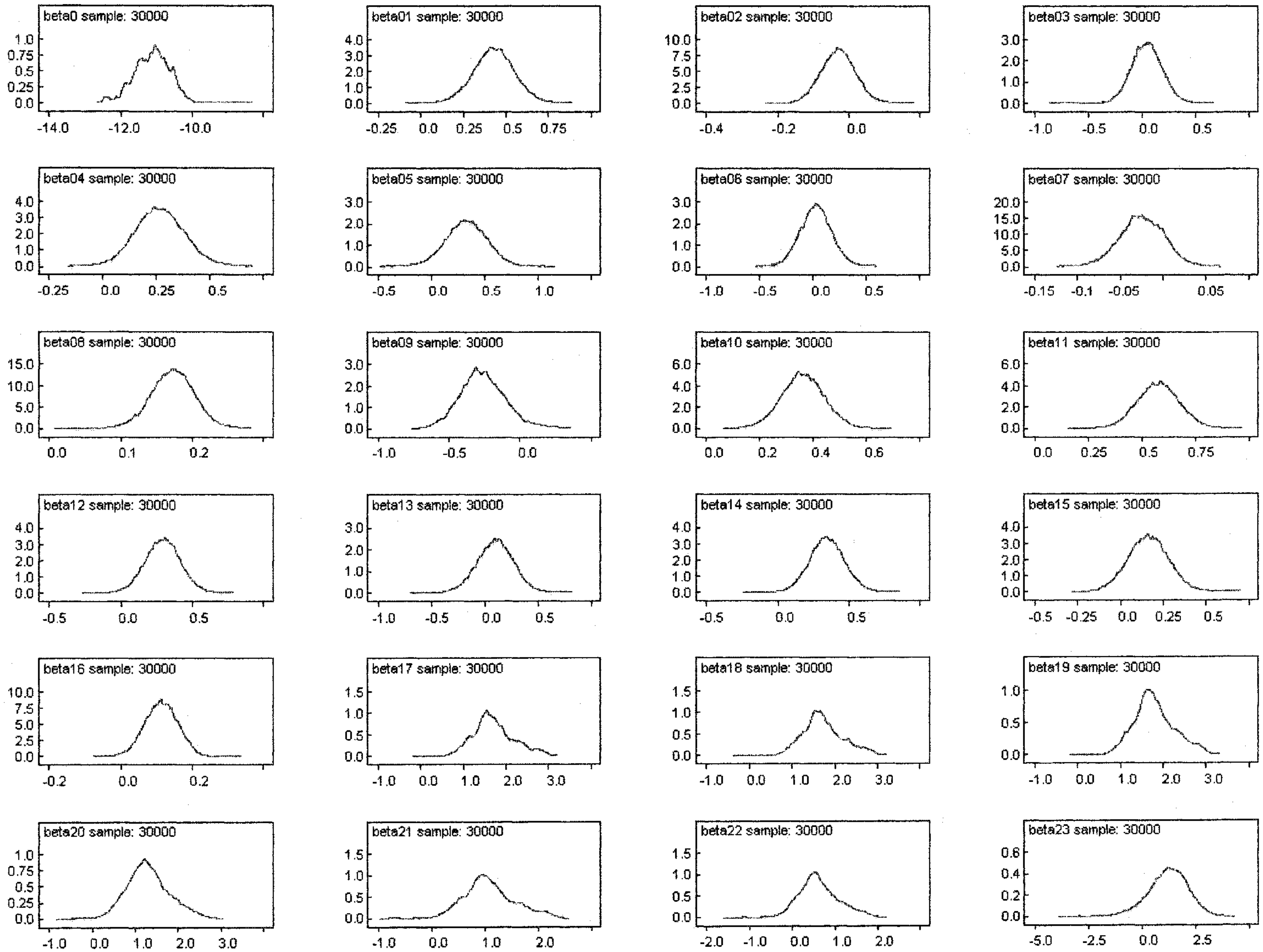


Figure 6.1. Exploratory model—density

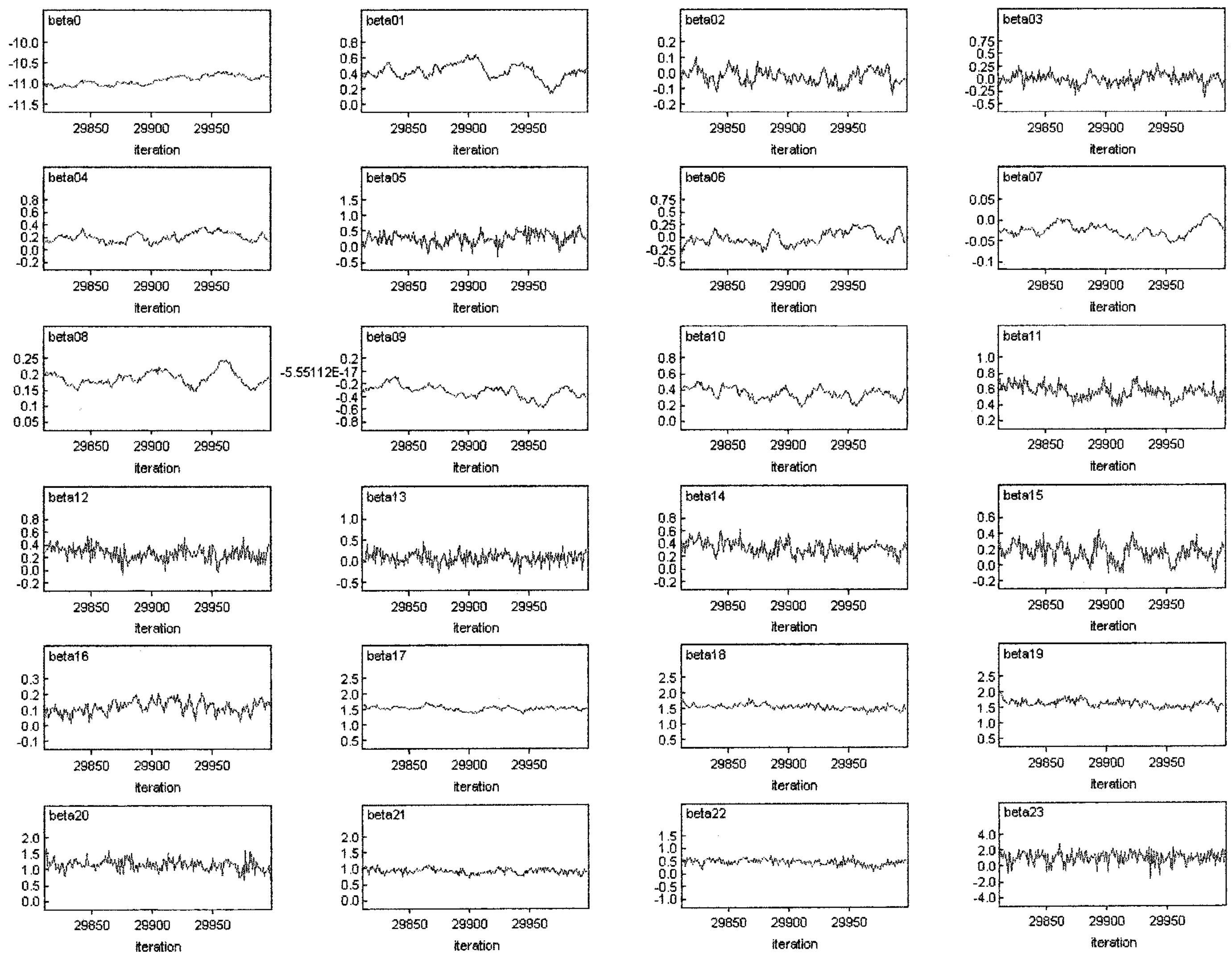


Figure 6.2. Exploratory model—trace

The history over all iterations is shown in Figures 6.3a and 6.3b. The history diagrams were output for each dummy variable. The time series diagrams were reasonably stable, though the intercept and the controls variables displayed more variability.

A final assessment of model convergence relies on examination of quantiles. Figure 6.4 displays the quantile diagrams for each dummy variable. These quantiles show the credible set values from the table over all iterations. The quantiles are stable over later iterations, which indicates convergence. However, the intercept and controls variables again indicate more variability.

Figure 6.5 displays possible levels of autocorrelation among the draws for each of the variables. Lengthier red lines indicate larger autocorrelation among the draws for the variable. The lags are repeated iterations (i.e., every 50th iteration). Again, the intercept and land use variables appear much different than the other variables. This indicates that the draws from these two conditional distributions will converge at a slower rate to the posterior distribution of interest.

The autocorrelations were used to determine values for thinning from the multiple chain run. Thinning was determined by choosing a lag value that seems to minimize autocorrelation across all variables. The lag value that seemed to minimize autocorrelation was 40, though it is difficult to tell with the controls and intercept having consistently high autocorrelation across all lags. Thus, every 40th iteration within the full model, the multiple chain draw was retained, resulting in a total of 625 nearly uncorrelated draws from each chain or 2500 total draws when 30,000 iterations were run. The idea behind thinning is to mimic the random sampling mechanism that produces the usual independently and identically distributed (i.i.d.) samples.

GENMOD–BUGS Comparison

For further assessment of the BUGS model script, results from BUGS were compared to results from GENMOD. GENMOD was run solely for this purpose. A correctly developed BUGS script provides results for the means similar to PROC GENMOD. Similarities between means, standard deviations, and significance should be evident. When comparing results, differences in base dummy values foster cautious interpretation.

On the whole, the values for each variable in BUGS compared favorably to GENMOD statistics, shown in Table 6.6. Cells highlighted in yellow indicate variables with the same base dummy level. Each of these compares favorably. The land use and controls variables were based on a different base dummy level between GENMOD and BUGS and cannot be directly compared. From these results, it appears that the final, multiple-chain model may be run with confidence that its results will be

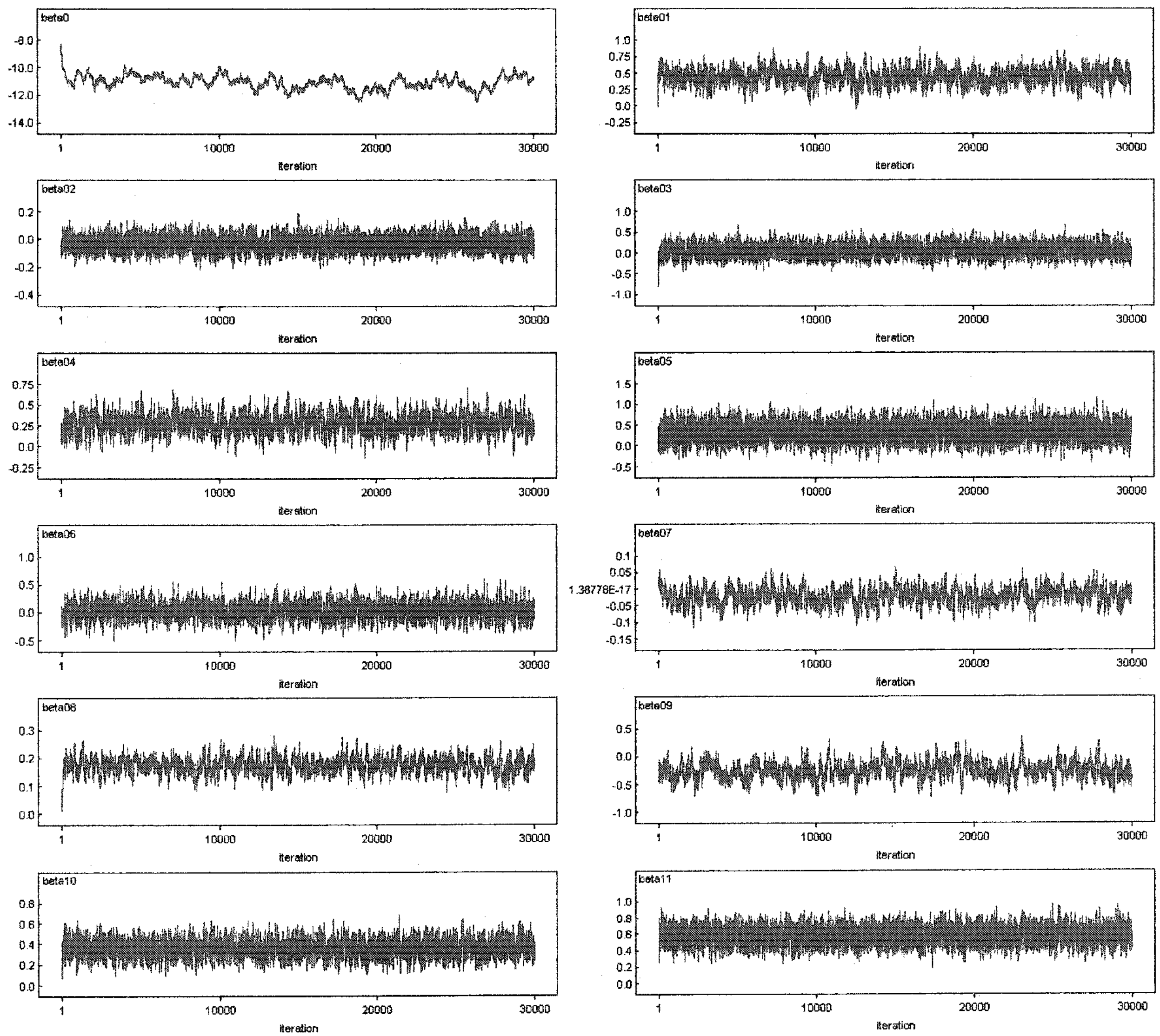


Figure 6.3a. Exploratory model—history (time series)

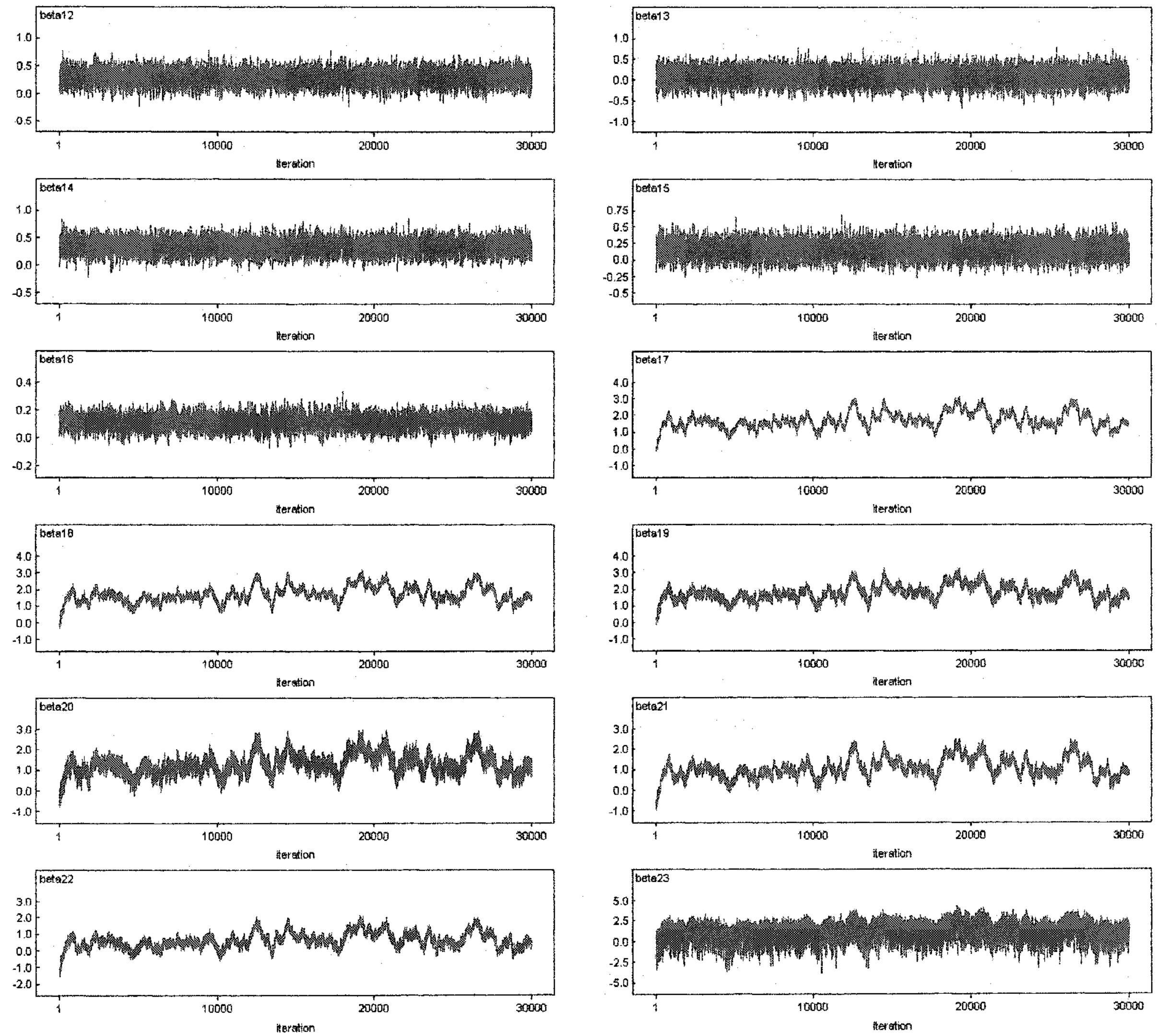


Figure 6.3b. Exploratory model – history (time series)

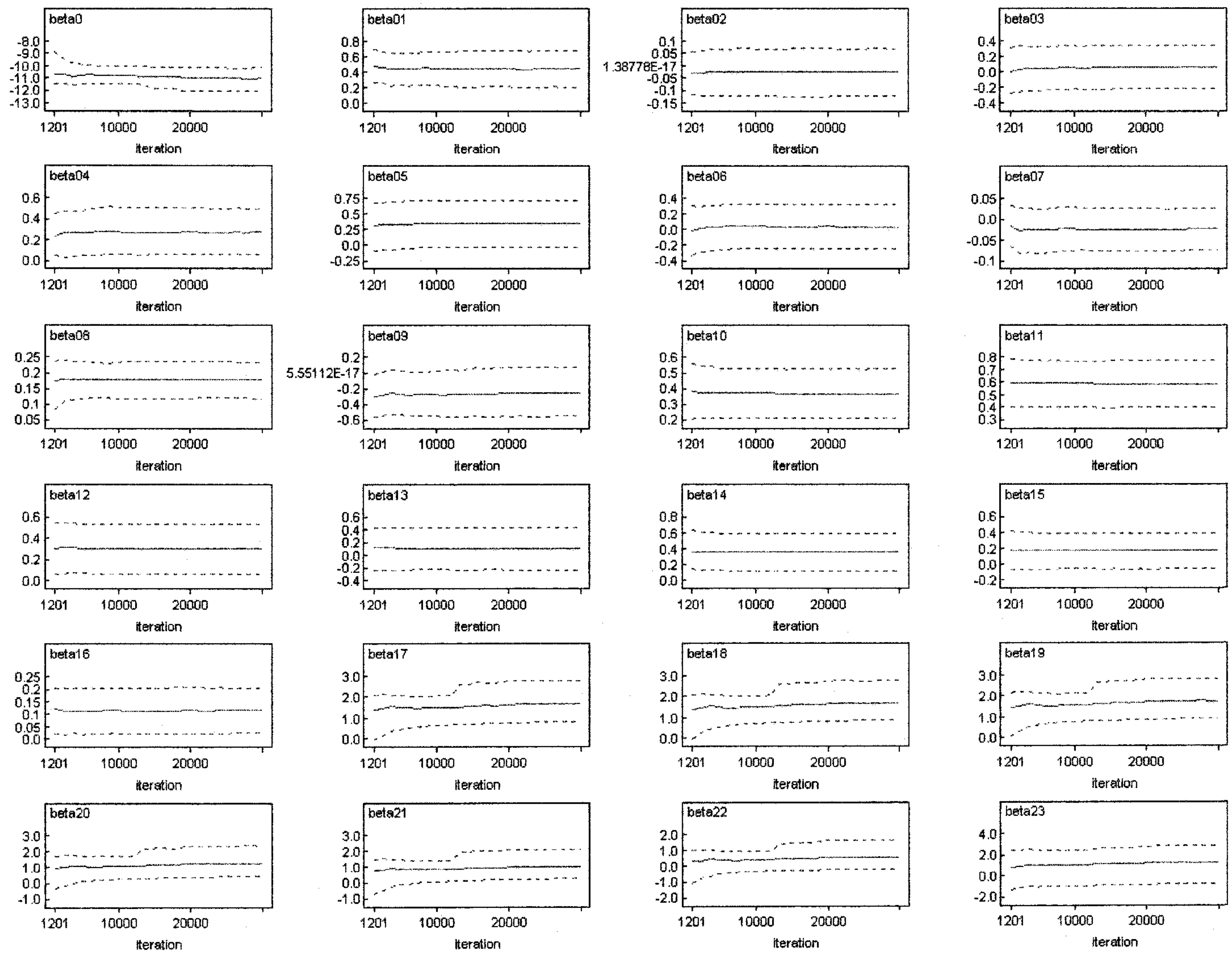


Figure 6.4. Exploratory model—quantiles

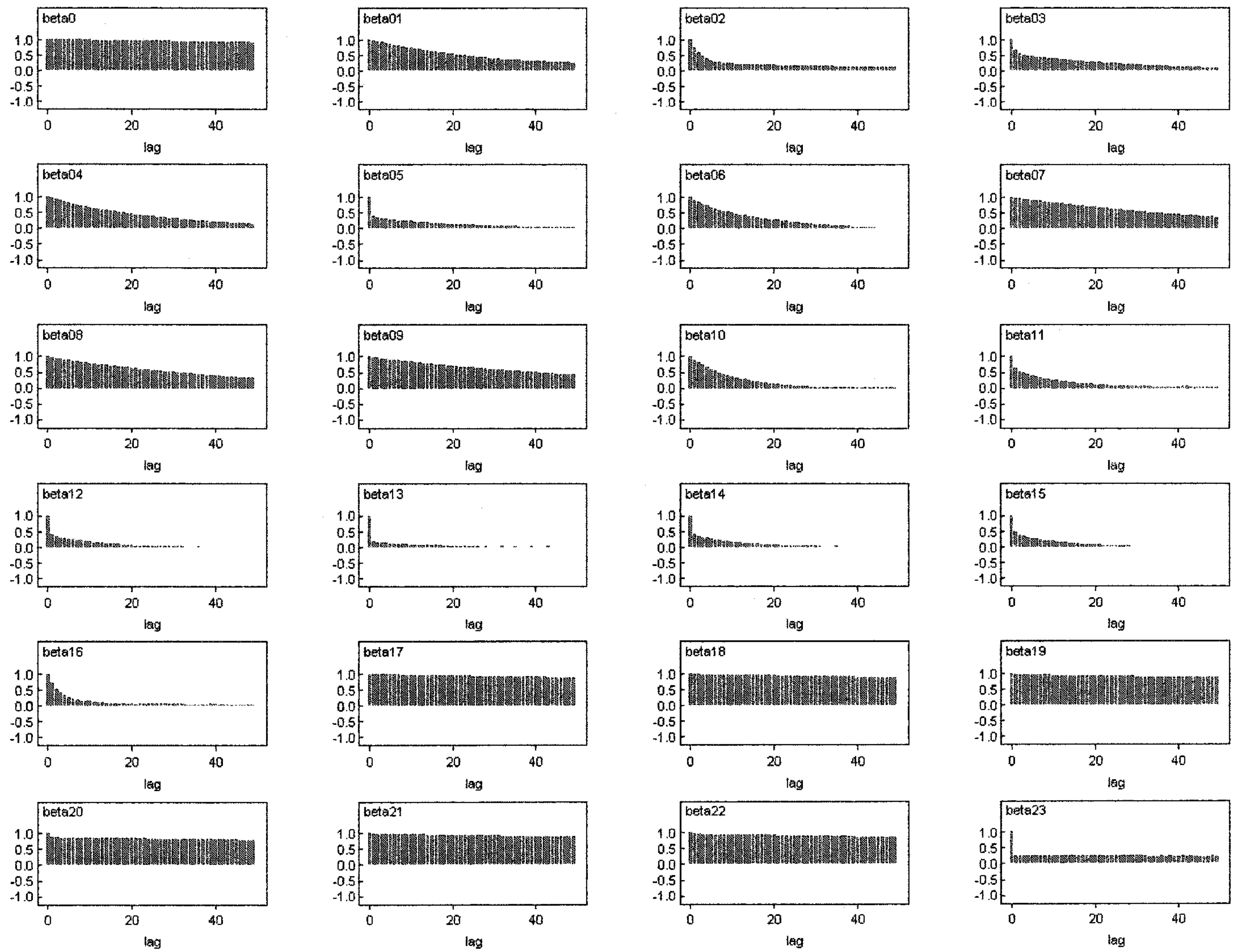


Figure 6.5. Exploratory model—autocorrelations

Table 6.6. GENMOD/BUGS comparison

		GENMOD		BUGS	
		Estimate	Standard Error	Mean	Standard Deviation
Intercept		-9.430	0.767	-11.120	0.493
Travel Direction: 4-way	1	0.421	0.114	0.430	0.118
Travel Direction: 3-way	2	0	0	0	0
Int. Class: municipal	1	-0.033	0.049	-0.031	0.048
Int. Class: non-municipal	2	0	0	0	0
Geometry: single-lane	1	0.040	0.140	0.047	0.141
Geometry: multi-lane	2	0.255	0.111	0.266	0.113
Geometry: single-, one-way	3	0.331	0.189	0.329	0.190
Geometry: multi-, one-way	4	0.021	0.142	0.026	0.144
Geometry: Offset T	5	0	0	0	0
Speed Limit: Major/Higher		-0.026	0.025	-0.025	0.025
Speed Limit: Minor/Lower		0.173	0.029	0.173	0.029
Topography: Level	1	-0.289	0.155	-0.266	0.154
Topography: Grade	2	0	0	0	0
Land Use: Residential	1	-0.162	0.117	0	0
Land Use: Business	2	0.196	0.092	0.361	0.079
Land Use: School	3	0.412	0.108	0.578	0.096
Land Use: Recreational	4	0.135	0.130	0.296	0.122
Land Use: Hospital	5	-0.057	0.178	0.099	0.167
Land Use: Church/Cemetary	6	0.187	0.129	0.348	0.120
Land Use: Parking Lot	7	0	0	0.163	0.116
Surface Type: ACC	1	0.112	0.047	0.115	0.047
Surface Type: PCC	2	0	0	0	0
Controls: None	0	-1.405	0.798	0	0
Controls: 4-way Signal	1	0.236	0.718	1.704	0.487
Controls: 3-way Signal	2	0.249	0.721	1.721	0.471
Controls: 1-/2-way Signal	3	0.318	0.724	1.791	0.477
Controls: 3-/4-way Stop	4	-0.148	0.730	1.309	0.496
Controls: 2-way Stop	5	-0.386	0.715	1.082	0.477
Controls: 1-way Stop	6	-0.846	0.725	0.627	0.460
Controls: Yield	7	0	0	1.207	0.930

Note: The yellow shaded values are the estimates for the β values that are comparable between the GENMOD and BUGS results. The red and blue outlined values indicate the difference in dummy variable definitions for land use and controls between GENMOD and BUGS.

appropriate. However, high levels of autocorrelation between the intercept term and the controls variables are indicated in Figure 6.5. Due to this possible autocorrelation, the model was modified.

Because the intercept term was easiest to remove, the model was converted to run without an intercept. The Controls: Yield variable was also dropped because very few (14) intersections had yield control and the intersections otherwise appeared similar to uncontrolled intersections. This change converted the interpretation of the Controls base variable to "little or no control."

Final BUGS Model Script

The script for the final model is very similar to the exploratory model, as shown in Appendix I. The final model uses the same model form, without the intercept term or a β for Controls: yield. The intercept was dropped from the model to reduce the identifiability problem that had increased the deviation of the controls regression coefficient. The same priors for each β are included and the data remain the same. However, because the final model was run with multiple chains, multiple initial β values are present in the final model script. Developed using a random number generator, these initial values begin each chain from a different point. This permits computing statistics that can be used to monitor the convergence of the chains to their stationary distribution.

Theoretically, the chains should converge and each chain should provide samples from the same posterior distribution. This does not guarantee a sample analogous to the classical independent and identically distributed (i.i.d.) draws but provides an Bayesian interpretation similar to it. The sample β draws from the BUGS run were used to generate a variety of results, including expected crash frequencies and rates. Using 2500 β draws, distributions were generated for crash frequency and rate for each intersection.

Inferential statistics for this final, multiple-chain model can be generated to assess model values, convergence, and fit. Table 6.7 displays the statistics for each non-base dummy value in the model. For proper interpretation, these values must be considered in light of the base dummy value for each category. As expected, these values are very similar to the exploratory model run and the GENMOD values. If the values were not similar, the model would require reassessment.

Figure 6.6 graphs the information shown in the table. The densities indicate the impact that a unit change in the associated variable would have on model results. The amount of the curve on either side of zero indicates the probability of an increase or decrease caused by that unit change. Vertical, dotted lines indicate the zero point on the graph for those density diagrams that that are near zero. The 100 percent term indicates those with β values all to one side of zero. The β values outlined in red have more equal amounts of their densities on either side of zero. Those β values outlined in orange have most of their density on one side of zero (e.g., perhaps 90%). Those β values outlined in green have nearly all their density on one side of zero (e.g., 95%).

To interpret the densities, first recall the β definitions indicated in Table 6.7. For example, β_{11} corresponds to Land Use: School and β_{13} corresponds to Land Use: Hospital. Both of these β values have a more even split of their densities with respect to zero. To roughly determine whether more crash rate can be expected around schools than in a residential area, visually inspect the area under the curve on either side of zero. For β_{11}, a roughly 60/40 split is evident, with 60 percent on the

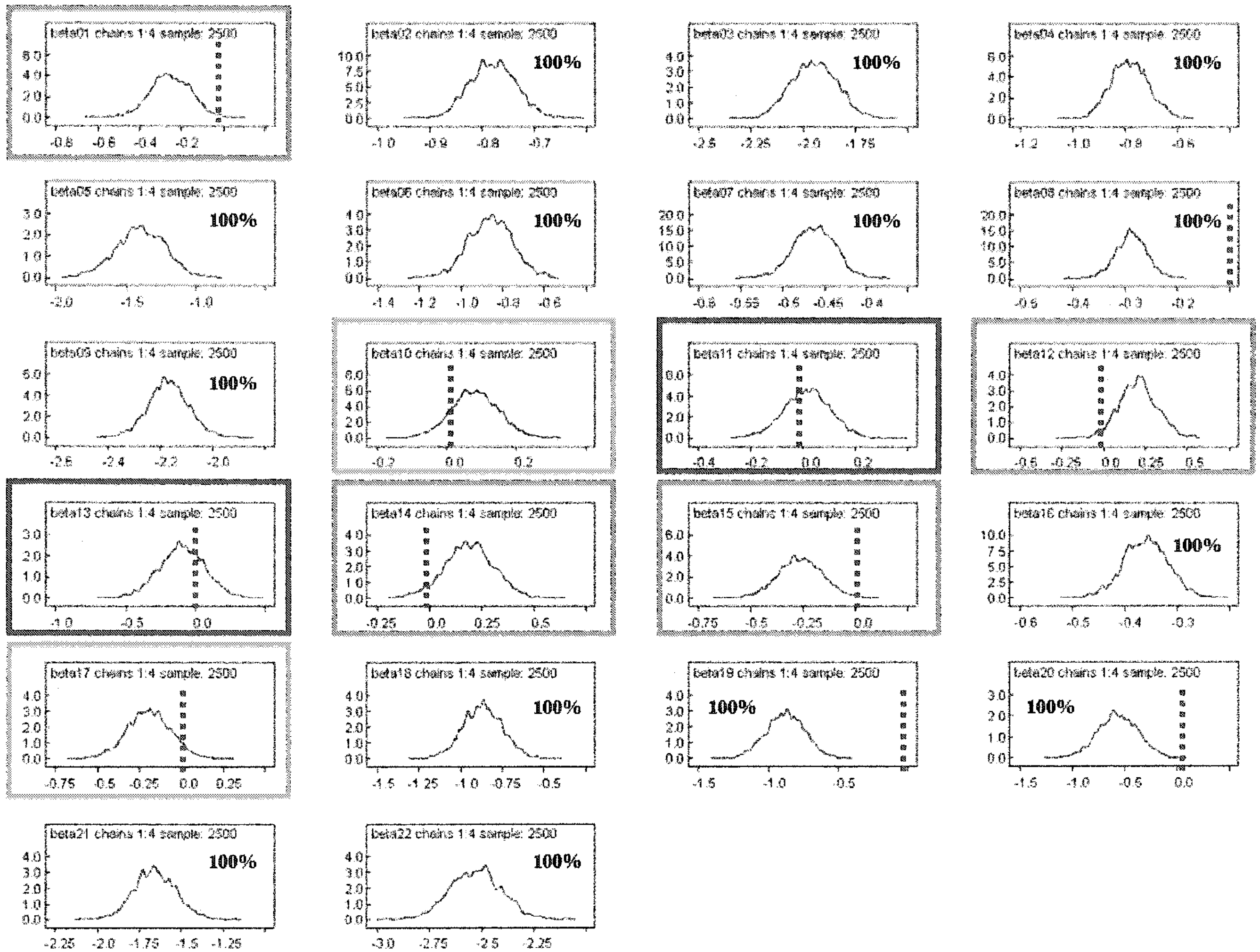
Table 6.7. Final, multiple-chain model—statistics

					Credible set		
Node	Variable	Mean	SD	MC error	2.5%	Median	97.5%
β_1	Travel Direction: 4-way	-0.253	0.09647	0.002001	-0.4459	-0.2548	-0.06539
β_2	Int. Class: municipal	-0.7778	0.04371	9.25E-04	-0.8593	-0.7781	-0.6929
β_3	Geometry: single-lane	-1.948	0.1078	0.002044	-2.153	-1.949	-1.734
β_4	Geometry: multi-lane	-0.781	0.0702	0.001205	-0.9123	-0.7835	-0.6403
β_5	Geometry: single-, one-way	-1.394	0.1705	0.003432	-1.74	-1.392	-1.072
β_6	Geometry: multi-, one-way	-0.8582	0.1047	0.001938	-1.073	-0.8559	-0.6539
β_7	Speed Limit: Major/Higher	-0.4623	0.02414	6.25E-04	-0.5093	-0.4619	-0.4166
β_8	Speed Limit: Minor/Lower	-0.2874	0.02864	7.34E-04	-0.3445	-0.2874	-0.2303
β_9	Topography: Level	-2.169	0.07736	0.001538	-2.324	-2.17	-2.011
β_{10}	**Land Use: Business**	0.08083	0.06699	0.001343	**-0.05007**	**0.07981**	**0.2142**
β_{11}	**Land Use: School**	0.0148	0.08707	0.001852	**-0.1566**	**0.01609**	**0.1846**
β_{12}	**Land Use: Recreational**	0.2047	0.1128	0.002017	**-0.01717**	**0.2042**	**0.4281**
β_{13}	**Land Use: Hospital**	-0.09318	0.1619	0.003282	**-0.4203**	**-0.0939**	**0.2206**
β_{14}	**Land Use: Church/Cemetery**	0.192	0.1165	0.002596	**-0.049**	**0.1923**	**0.4174**
β_{15}	Land Use: Parking Lot	-0.2619	0.105	0.001943	-0.4641	-0.2624	-0.05106
β_{16}	Surface Type: ACC	-0.3596	0.04209	8.59E-04	-0.444	-0.3591	-0.2767
β_{17}	**Controls: 4-way Signal**	-0.1934	0.1327	0.002906	**-0.4578**	**-0.1936**	**0.06527**
β_{18}	Controls: 3-way Signal	-0.8674	0.1201	0.002426	-1.109	-0.8668	-0.6324
β_{19}	Controls: 1-/2-way Signal	-0.8791	0.1382	0.00277	-1.155	-0.8758	-0.6117
β_{20}	Controls: 3-/4-way Stop	-0.5629	0.1911	0.004611	-0.9443	-0.5654	-0.1938
β_{21}	Controls: 2-way Stop	-1.657	0.1272	0.002574	-1.906	-1.66	-1.404
β_{22}	Controls: 1-way Stop	-2.526	0.1246	0.002721	-2.765	-2.525	-2.28

Note: The mean and standard deviation (shaded grey) are the Bayes estimates for the β values and the standard deviation, or uncertainty, in the estimates. The bolded variables are those that are not 100% on one side of zero, as indicated by the credible set values. Yellow highlighted values have the preponderance of their distribution on one side of zero. Pink highlighted values have a more equal split on either side of zero. The amount that each β value falls to one side of zero is indicative of the "significance." Thus, variables highlighted in pink are very likely "not significant", while those highlighted in yellow would be almost significant if we were to interpret results from within a classical framework.

positive side. This indicates that there is no noticeable difference between school area and residential area on crash rate. For β_{13} the split is reversed. This indicates that Land Use: Hospital has a 60% chance of increasing crash history. This non-intuitive (e.g., reverse) interpretation of the β values is due to model development assumptions.

BUGS output that indicates model strength and convergence can be generated. An additional multiple-chain parameter, the Gelman-Rubin statistic, is available. This parameter is analogous to the standard linear regression R^2 value. Within each statistic diagram, results from each chain are displayed using different colors. The desired result is that chains should be indiscernible. If only minor variations may be visually detected, the chains can be considered similar, which is desired.



Note: Red boxes indicate densities with equal areas on either side of zero. Yellow boxes indicate densities with the majority of their area on one side. Green boxes indicate densities with nearly all their area on one side of zero.

Figure 6.6. Final, multiple-chain model—density

Figure 6.7 shows that, for each β, the last 200 iterations have strong convergence, as the variability is relatively small over the displayed range. Note that the between chain differences are minor, even for those β's with multiple discernible chains. Though trace diagrams are initial indicators of convergence, other measures of convergence should be reviewed to verify the assessment and to determine model strength.

Figure 6.8a provides a verification of trace results for the first 12 β's. For the final 10 β's, similar results are displayed in Figure 6.8b. Similarity between chains is evident for all 22 β's, indicated by the observation that all chains oscillate about a central value (e.g., picking out one chain from another is impossible). The controls variables (e.g., β's 17 through 22) no longer display non-uniformity, as they had in the exploratory model.

Figure 6.9 further verifies these results using quantile diagrams. Model convergence is indicated both by the central lines (i.e., the means) and the 95% confidence intervals. The majority of the quantile diagrams are relatively smooth and stable, with all the diagrams smoothing out.

Figure 6.10 displays Gelman-Rubin (GR) results. The diagrams indicate convergence and strength for each dummy variable. Convergence for each variable is indicated by a relatively stable set of lines over all iterations. GR values that converge to one on the vertical scale indicate variable strength. GR values greater than one indicate overdispersion. All the GR diagrams converge to one, with some having slightly more variability. The diagrams outlined in red have some non-convergence indicated for the first 10,000 iterations. Perhaps a longer burn-in might have been advisable. The diagrams outlined in orange seem to have discernible differences between changes, though not greatly so. This indicates that these variables might be less reliable and require further consideration. However, previous diagrams (i.e., trace, history, quantiles) have not indicated problems. The diagrams outlined in green have slight aberrations along their convergence. Again, previous diagrams indicated no problems; therefore, this is probably not an issue.

Figure 6.11 shows autocorrelations for each β value. None of the diagrams indicates any major autocorrelation. This supports that information provided by the previous diagrams. Note that previously the autocorrelations for the intercept and controls variables were large. The intercept is not included and the controls variable autocorrelations are very small, indicating model improvement.

Hierarchical Bayes Results

A large variety of results are possible from Bayesian analysis, dependent on the number of covariates and covariate levels. An illustrative set of results conveys the possibilities afforded by Bayesian analysis for network screening purposes.

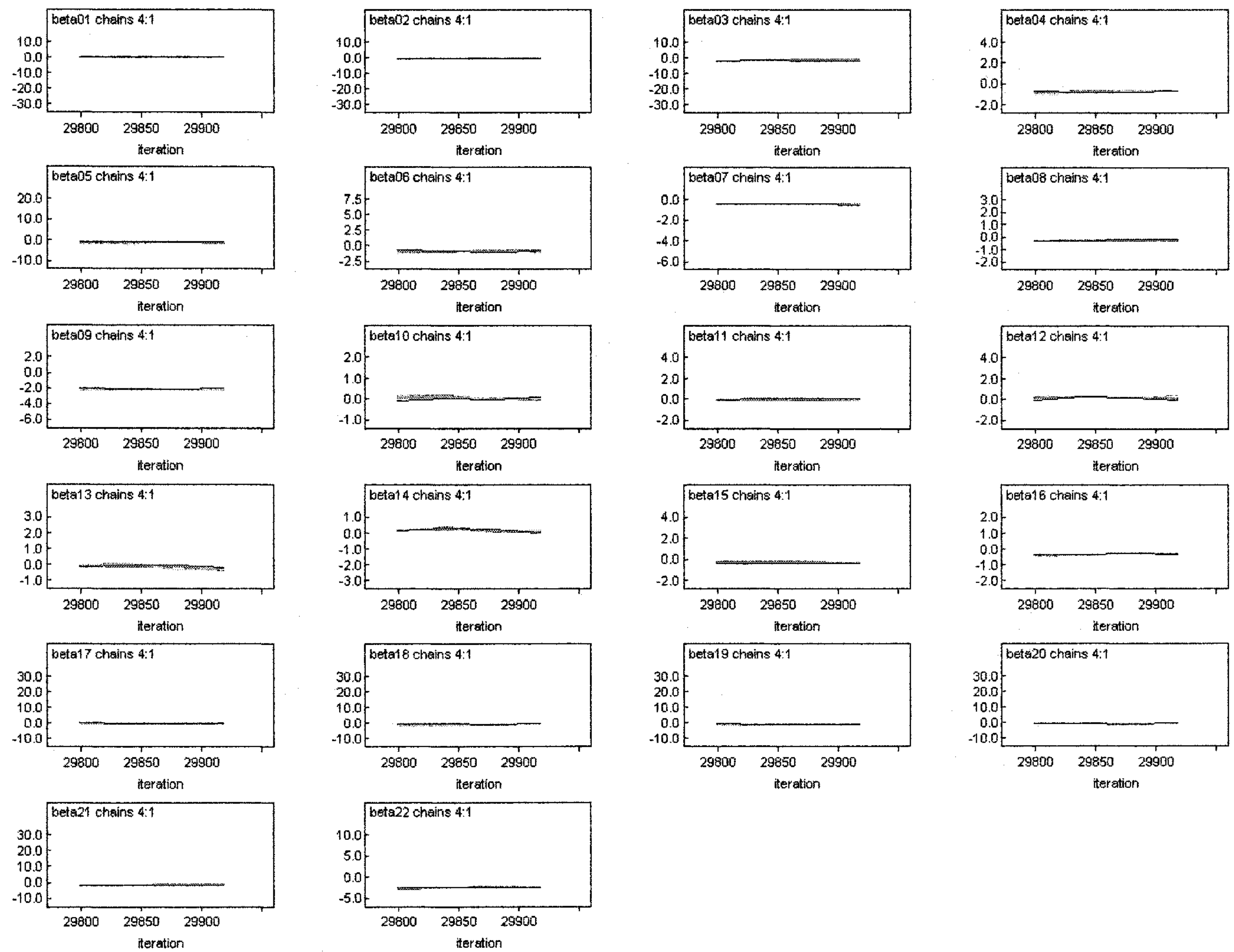


Figure 6.7. Final, multiple-chain model—trace

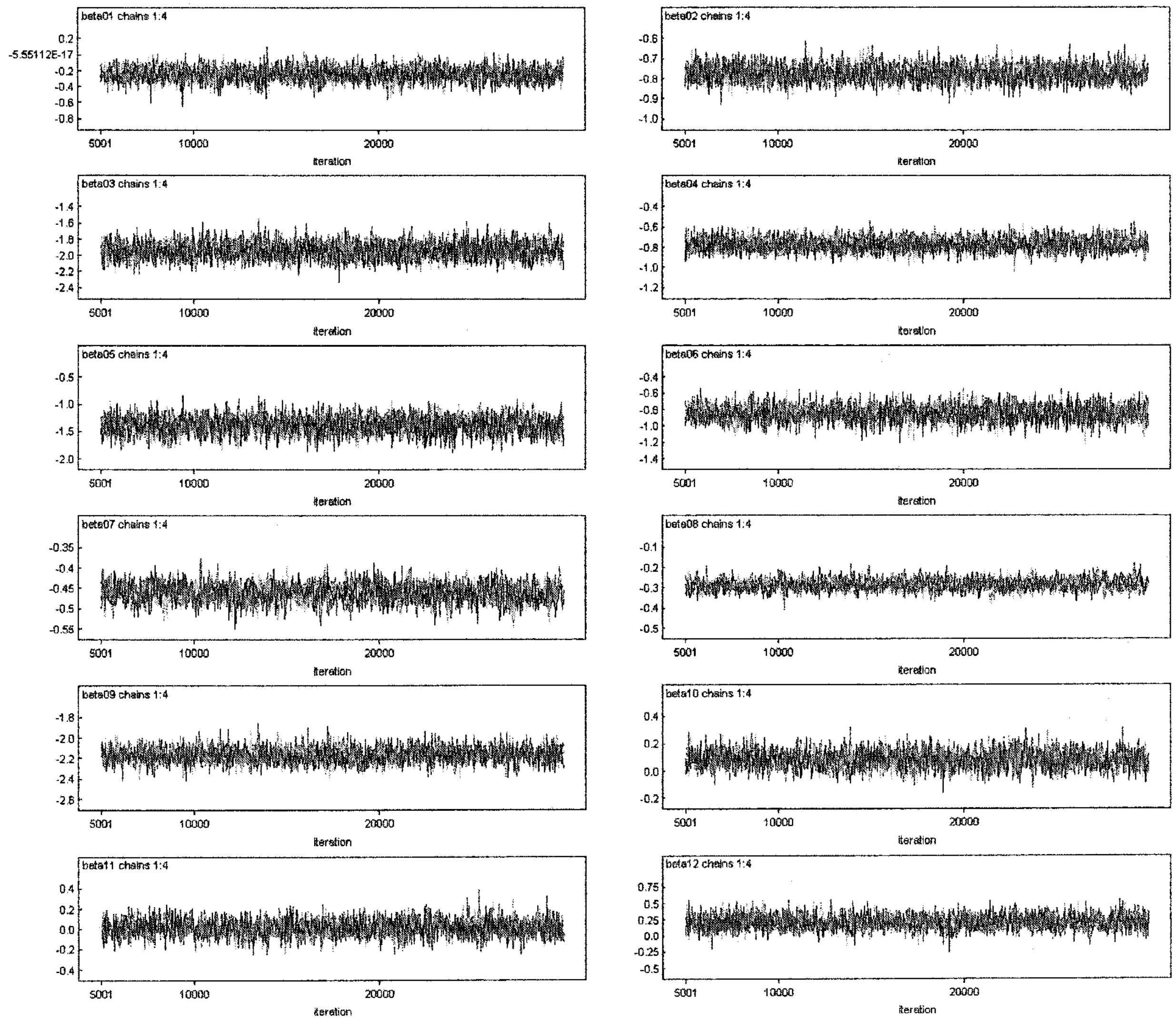


Figure 6.8a. Final, multiple-chain model—history (time series)

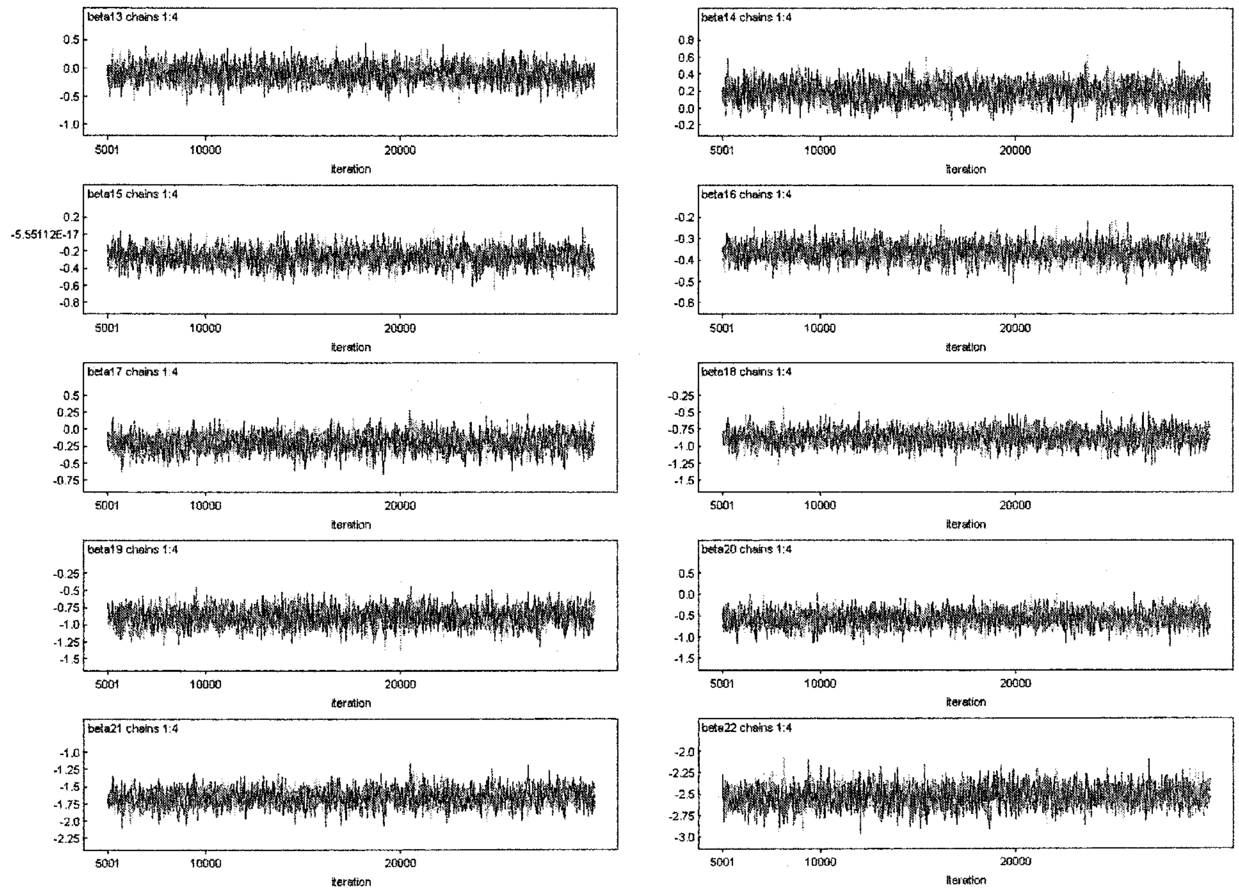


Figure 6.8b. Final, multiple-chain model—history (time series)

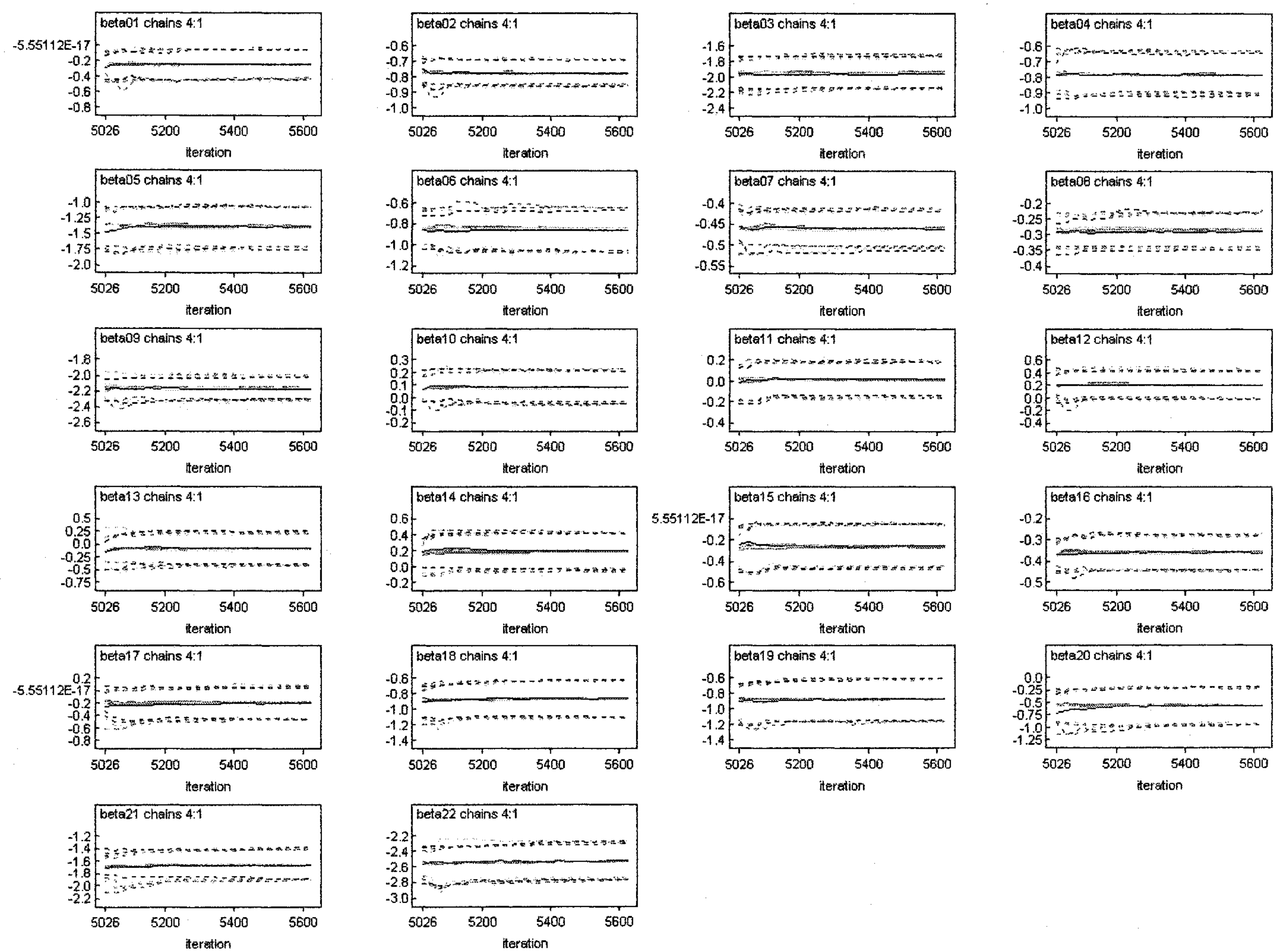
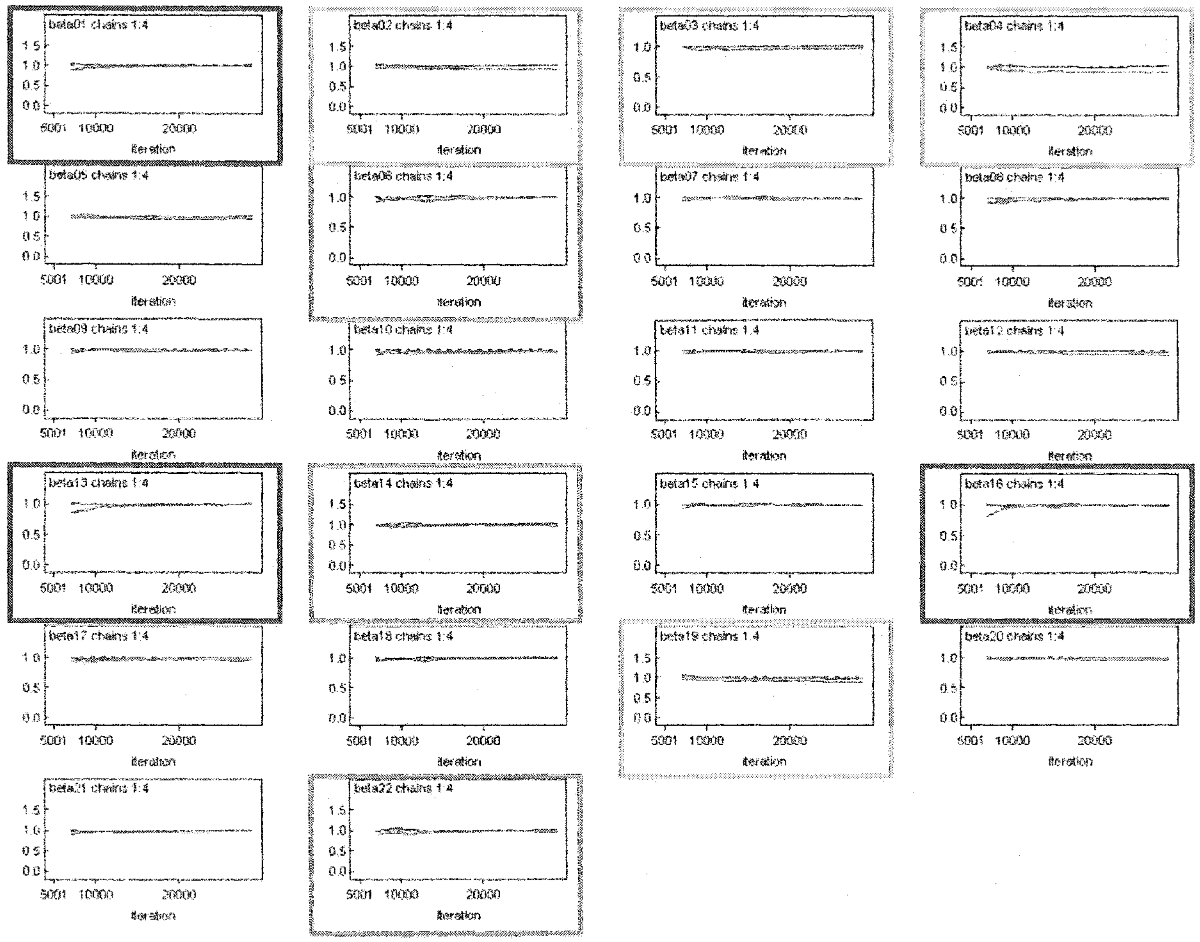


Figure 6.9. Final, multiple-chain model—quantiles



Note: Red boxes indicate GR diagrams with non-convergence within the first 10,000 iterations. Yellow boxes indicate GR diagrams with some discernible between-chain differences. Green boxes indicate GR diagrams with slight aberrations.

Figure 6.10. Final, multiple-chain model—Gelman-Rubin

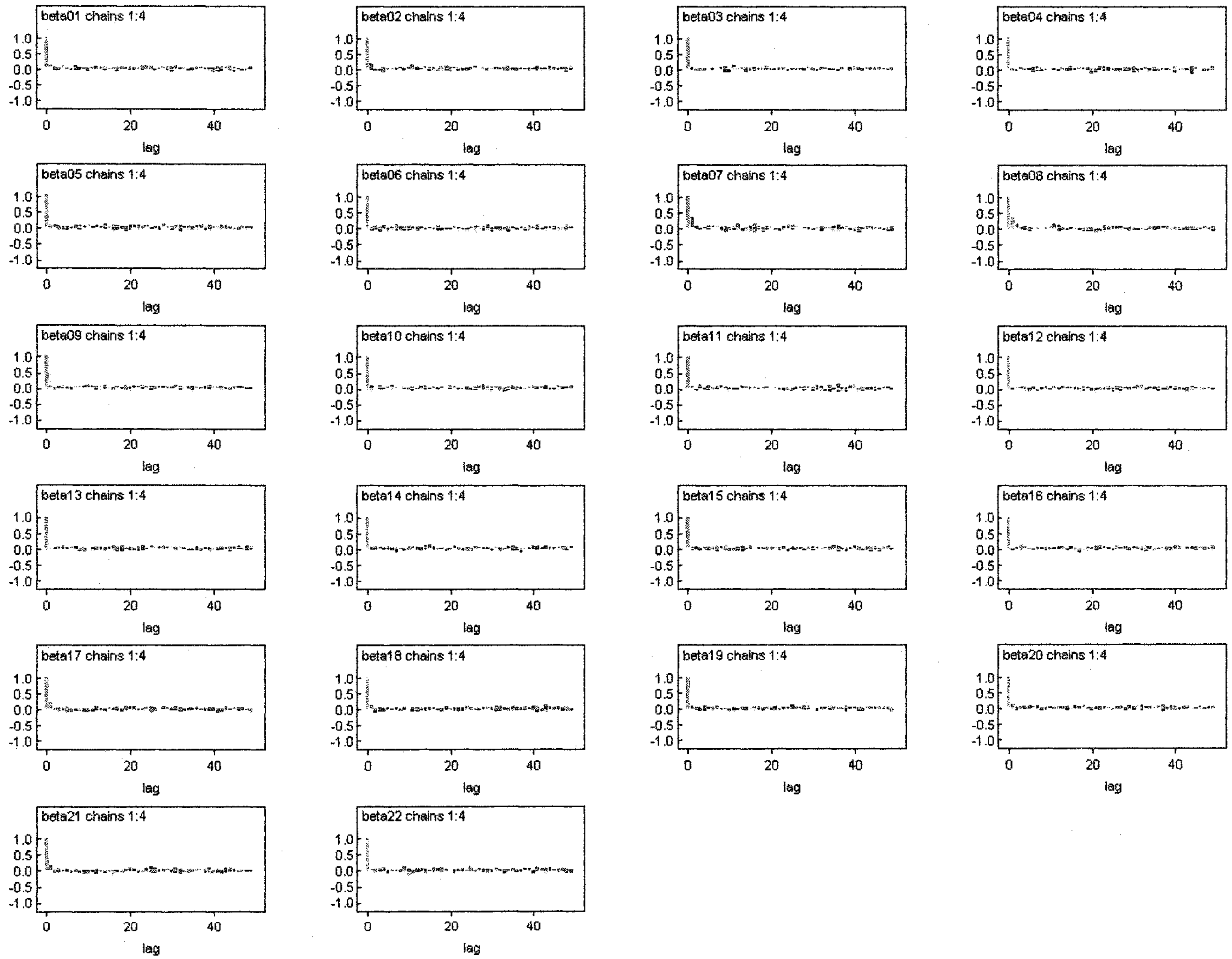


Figure 6.11. Final, multiple-chain model—autocorrelations

Expected values

Bayesian expected value analysis has enormous potential for network screening. Like other methods, Bayesian analysis outputs expected values (i.e., means), variances, standard deviations, and other statistical measures for the response variable. Unlike other methods, Bayesian analysis provides distributions of the expected values.

Expected values analysis is currently promoted (Harwood et al. 2002; Hauer 1996a,c; MRI 2002a,b,c,d,e,f,g;2003a,b,c,d,e; Parker 1991; Persaud and Hauer 1984) as a better method for assessing safety. Expected values of crash frequencies, when compared to actual frequency, define "sites with promise" (Hauer 1996b; Hauer et al. 2002). Table 6.8 displays the top 20 of the 1031

Table 6.8. Expected values—crash frequency

ID	City	1998 crashes	Mean (expected crash frequency)	Maximum	Minimum	Range	Variance	Standard deviation	Difference[a]	Absolute value of difference	% absolute difference
11	DSM	25	14.07	16.16	11.99	4.17	0.39	0.63	-10.93	10.93	77.74%
177	DSM	24	12.32	15.37	9.54	5.83	0.82	0.90	-11.68	11.68	94.85%
97	DSM	22	6.15	7.41	5.11	2.30	0.13	0.36	-15.85	15.85	257.77%
5020	Ames	21	3.55	4.25	2.83	1.42	0.04	0.20	-17.45	17.45	490.90%
5066	Ames	21	5.77	9.07	3.63	5.44	0.45	0.67	-15.23	15.23	264.17%
117	DSM	21	10.54	14.82	6.45	8.36	1.31	1.14	-10.46	10.46	99.30%
178	DSM	21	9.39	14.24	6.16	8.08	1.19	1.09	-11.61	11.61	123.59%
140	DSM	21	6.12	7.52	4.91	2.61	0.13	0.35	-14.89	14.89	243.42%
121	DSM	20	15.95	19.52	13.09	6.43	0.78	0.88	-4.05	4.05	25.37%
10	DSM	20	17.51	21.43	14.37	7.06	0.94	0.97	-2.49	2.49	14.21%
93	DSM	19	8.67	11.52	6.72	4.80	0.44	0.67	-10.33	10.33	119.04%
257	DSM	19	5.06	7.02	3.33	3.69	0.23	0.48	-13.94	13.94	275.23%
98	DSM	19	5.69	6.82	4.76	2.06	0.08	0.29	-13.31	13.31	233.83%
139	DSM	19	15.80	18.60	13.54	5.06	0.52	0.72	-3.20	3.20	20.23%
85	DSM	19	4.23	5.14	3.64	1.51	0.04	0.21	-14.77	14.77	349.02%
94	DSM	19	11.50	13.73	9.52	4.20	0.42	0.64	-7.50	7.50	65.19%
45	DSM	18	6.30	9.61	4.51	5.10	0.40	0.63	-11.70	11.70	185.65%
58	DSM	18	9.60	11.00	8.23	2.78	0.16	0.41	-8.40	8.40	87.58%
27	DSM	18	8.87	10.59	7.35	3.24	0.25	0.50	-9.13	9.13	102.85%
2	DSM	18	6.84	8.28	5.71	2.57	0.13	0.35	-11.16	11.16	163.07%

[a] The Difference column was calculated by subtracting the 1998 Crashes column from the Mean (expected crash frequency) column.

test sites, sorted in descending order by 1998 crash frequency. Differing from conventional SICL analysis, here it is not implied that these are the 20 "worst" sites.

The mean, or expected crash frequency, for most of the 20 sites is not close to the actual crash frequency (i.e., 1998 crashes). The expected values result from the Bayesian method of pooling sites with similar characteristics. This pooling mitigates wide variations in crash frequencies that might occur from year to year at each site (i.e., regression-to-the-mean). The expected crash frequency considers both the individual site characteristics and site characteristics from similar sites to generate a "smoothed" expectation for each site.

Because the Bayesian method produces samples from a distribution describing each site, the results are informative. In addition to point estimates, insight into each site's crash frequency is provided. Maximums, minimums, ranges, variances, and standard deviations result naturally from a sample set. Hypothesis tests on these values can be performed. An evaluation of "how much worse" one site is than another is enabled. This is a potentially valuable assessment tool.

The difference between expected crash frequency and actual crash frequency is given, calculated by subtracting actual frequency from expected frequency. A positive value indicates better than expected performance and a negative difference indicates worse than expected.

Density diagrams, which provide a visualization of the table statistics, can easily be constructed. Potential directions for analyses (e.g., signalized intersections) can be quickly determined. Using the sample expected frequency values, diagrams can be constructed for individual sites, multiple individual sites, or grouped sites (e.g., sites with similar characteristics).

Figure 6.12 illustrates differences in expected crash frequencies between sites grouped by control type and configuration. As might be expected, four-way, signalized intersections experience a much higher frequency of crashes than do other intersections. This is most likely due to the higher volumes at these intersections. In fact, one of the warrants for signal installation is crash history. Other signalized intersection groupings (i.e., three-way and one- or two-way) have higher crash frequency than the unsignalized categories. The groupings to the left are ordered as expected given warrants and volumes, with increasing control generally having higher expected crash frequencies.

In this example, most of the distribution tails do not overlap. This provides visual verification of the relative significance of the differences between groups as well as an assessment of "how much worse" one category is than another. However, three-way, signalized intersections and one- or two-way signalized intersections largely overlap. This indicates that the differences between the two groupings are essentially negligible, perhaps allowing these control categories to be grouped in future analyses.

These assessments can be used to compare individual sites in a like manner. For example, Figure 6.13 displays the expected crash frequencies for all four-way, signalized intersections. Because there are 191 four-way, signalized intersections in the database, the graph does not lend itself to individual interpretation of sites. However, it is evident that considerable differences exist within the four-way,

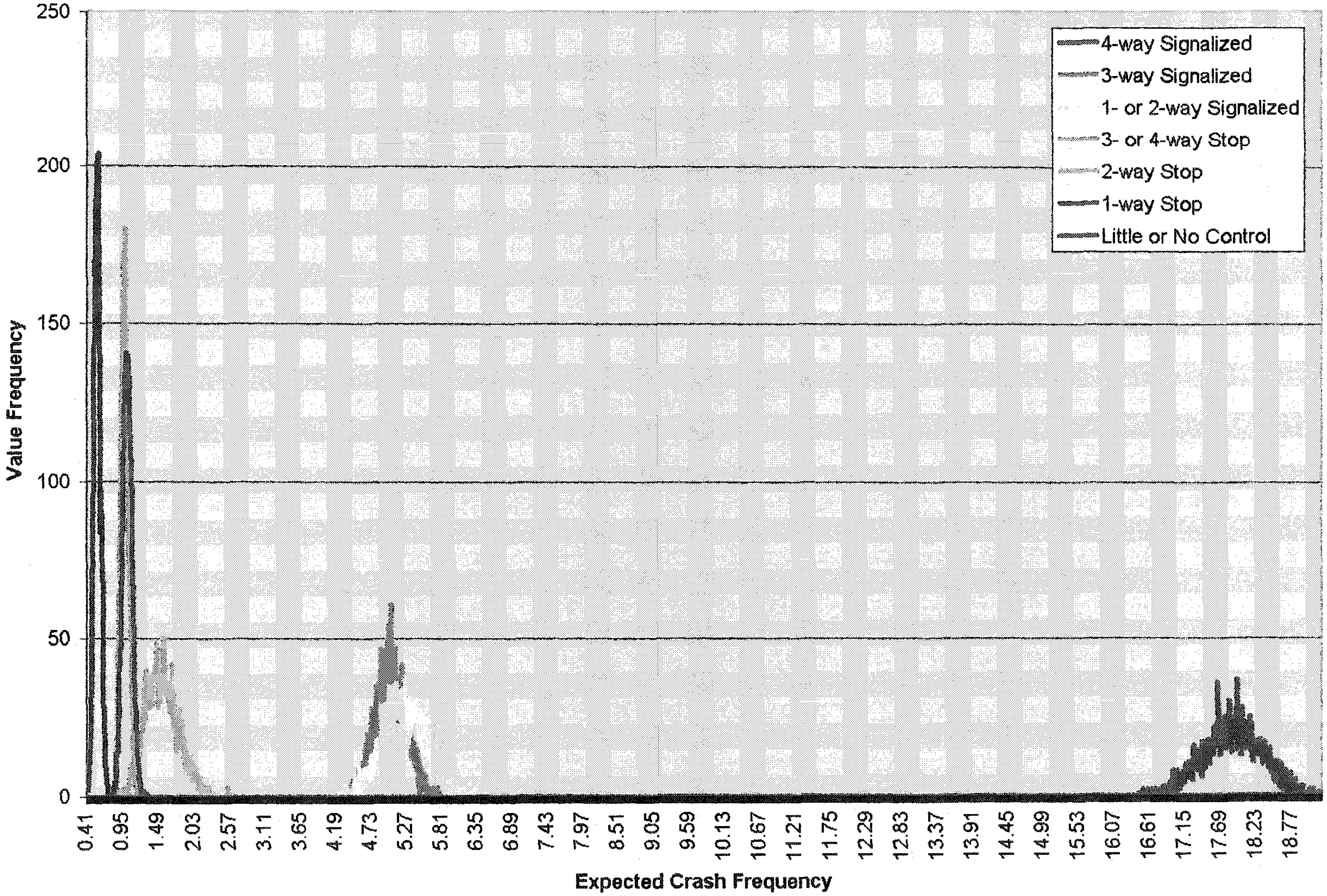


Figure 6.12. Expected frequency values—grouped sites densities: controls

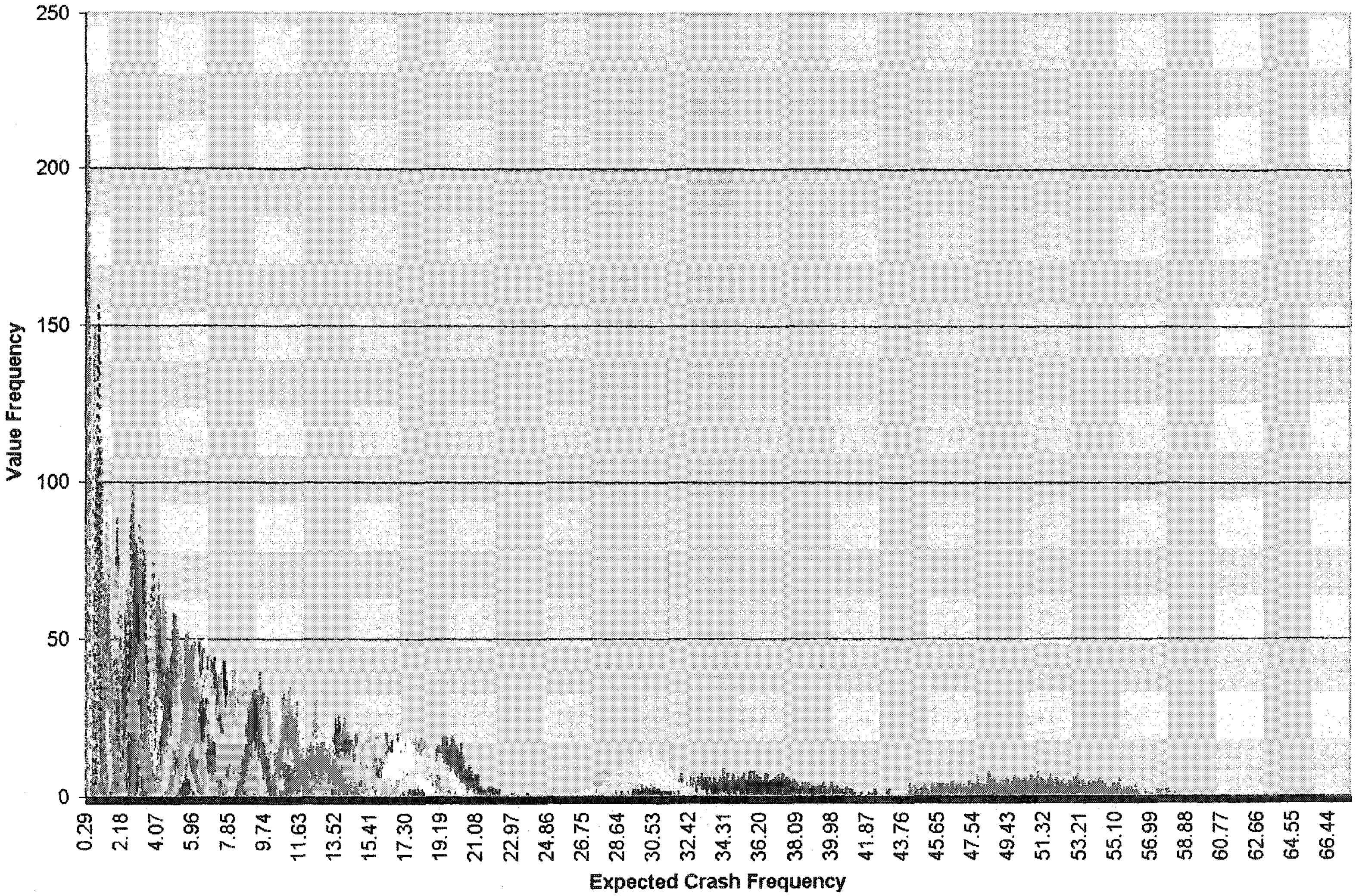


Figure 6.13. Expected frequency values—individual sites: four-way, signalized

signalized intersection grouping. A few of the sites have much greater expected crash frequencies. Some factor other than four-way signalization must account for the difference. These sites may be further grouped by expected crash frequency and these subgroups can be further analyzed. Similar groupings based on the other model covariates are also possible.

Density diagrams provide a visual verification of the confidence in a particular point estimate. Because the densities display the spread of values, they indicate the uncertainty with respect to the mean for each grouping. For example, the four-way, signalized intersection grouping displays greater spread than the one-way, stop-controlled or two-way stop-controlled intersection grouping. This implies that more certainty about the true value of the mean exists for the latter.

The expected crash frequencies can be grouped in many different fashions. For example, the groupings from Figure 6.12 could be analyzed further by selecting one grouping and constructing densities with respect to some other model covariate. Selecting all of the four-way, signalized intersections, groupings based on geometry, zoning, or some other factor could be displayed in a density diagram. This drill-down could be continued over multiple factors of interest, searching for causes of higher crash frequencies within the four-way, signalized intersection subset.

Another grouping option is selecting sites that are either exactly the same or similar, which could be defined as some percentage of attributes being the same (e.g., 90% or more). Figure 6.14 displays

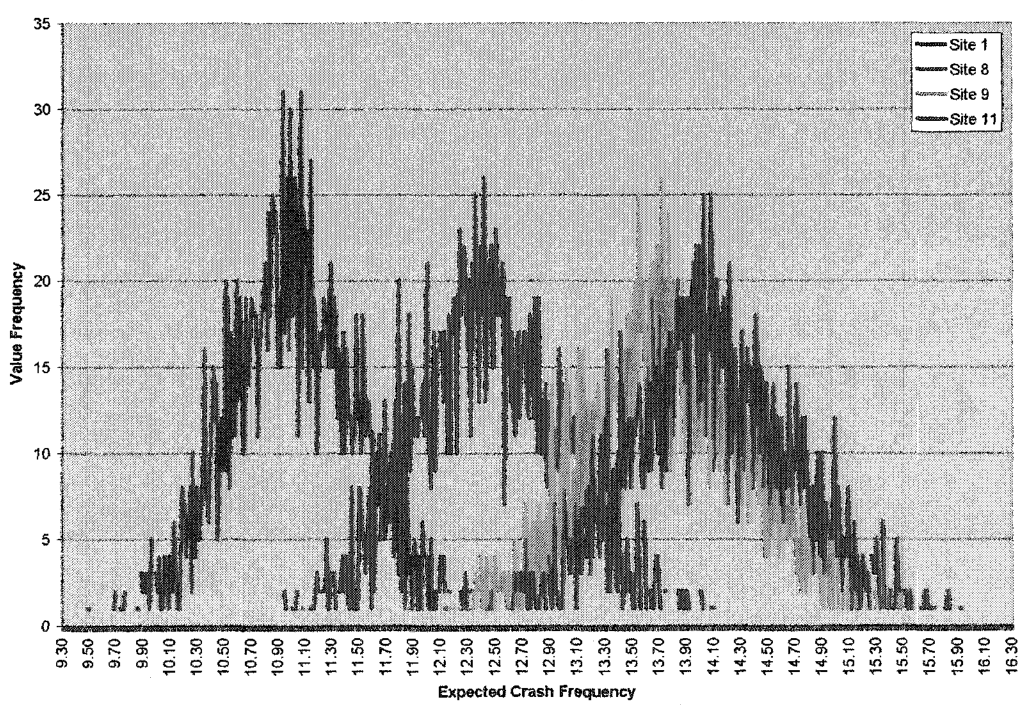


Figure 6.14. Expected values—similar site densities

a grouping of four sites that have exactly the same covariate values, other than the volume and actual crash frequency (i.e., 1998 crash frequency). These sites have these features: four-way, non-municipal, multi-lane, signalized, level topography, in a business area, speed limits of 40 and 30 mph, and volumes greater than 30,000 vehicles per day (vpd). The crash history and volume for each site in 1998 are as follows:

- Site 1: 13 crashes and 32,440 vpd
- Site 8: 8 crashes and 36,650 vpd
- Site 9: 16 crashes and 40,485 vpd
- Site 11: 10 crashes and 41,400 vpd

Site crash history and volume strongly influence expected crash frequency. Sites with large frequencies and volumes are brought toward normal levels for similar sites, allowing comparisons between expected and actual crash frequency to determine sites requiring further examination.

In Figure 6.14, sites 9 and 11 are similar. Their densities overlap to a high degree. However, site 11 has slightly higher expected crash frequencies across its distribution and has a higher mean value. Site 8 has noticeably less expected crash frequency than sites 9 and 11 but is higher than site 1. However, some uncertainty remains between site 8 and the other sites due to some overlap in the densities. This uncertainty is minimal because the tails overlap only slightly compared to the entire density area. The expected crash frequency for site 1 is certainly lower than that for sites 9 and 11. This is evident by the minimal overlap between the densities.

Sorted in descending order by 1998 crash rate, rates for 20 of the 1031 sites are displayed in Table 6.9. Many researchers have questioned the use of crash rate, due to its non-linear nature when compared to crash frequency (Hauer 1986,1996; Hauer et al. 1986,1988,2002; Hauer and Persaud 1984; ITE 1999). A common reason given for rates is that frequency favors high volume sites and crash rate controls for the volume. Others argue that the difference between expected crash frequency and actual crash frequency is a better option. Expected crash rate retains at the least some historic interest. Similar statistics can be calculated for the expected crash rate distributions for each site.

Comparing Table 6.9 to Table 6.8, it is evident that the two methods of ranking (i.e., frequency and rate) previously used by practitioners do not return similar results. Only five sites (45, 93, 257, 5020, and 5066) appear in both tables. This difference in results is widely known.

Density diagrams can be constructed using rates, as shown in Figure 6.15. Note that the individual categories are more closely spaced, with more overlap between more groups. Sites with

Table 6.9. Expected values—crash rates

ID	City	1998 rate	Mean (expected crash rate)	Maximum	Minimum	Range	Variance	Standard deviation	Difference[a]	Absolute value of difference	% absolute difference
5160	Ames	3.96	0.56	0.81	0.34	0.47	0.00	0.07	-3.41	3.41	609.79%
5172	Ames	3.71	0.48	0.63	0.35	0.28	0.00	0.04	-3.23	3.23	676.81%
1695	DSM	3.21	0.19	0.33	0.10	0.22	0.00	0.03	-3.02	3.02	1605.72%
2014	DSM	3.05	0.39	0.72	0.22	0.49	0.00	0.07	-2.66	2.66	689.50%
5162	Ames	2.91	0.56	0.81	0.34	0.47	0.00	0.07	-2.35	2.35	420.66%
93	DSM	2.82	1.29	1.71	1.00	0.71	0.01	0.10	-1.53	1.53	119.04%
282	DSM	2.81	1.35	1.83	0.94	0.89	0.02	0.13	-1.46	1.46	108.44%
257	DSM	2.62	0.70	0.97	0.46	0.51	0.00	0.07	-1.92	1.92	275.24%
5020	Ames	2.60	0.44	0.53	0.35	0.18	0.00	0.02	-2.16	2.16	490.90%
5124	Ames	2.58	0.56	0.81	0.34	0.47	0.00	0.07	-2.02	2.02	361.40%
26	DSM	2.48	1.00	1.14	0.87	0.27	0.00	0.04	-1.47	1.47	146.92%
2013	DSM	2.47	0.65	0.96	0.44	0.52	0.01	0.07	-1.82	1.82	277.89%
1164	DSM	2.42	0.07	0.10	0.05	0.05	0.00	0.01	-2.35	2.35	3504.89%
45	DSM	2.41	0.84	1.29	0.60	0.68	0.01	0.08	-1.57	1.57	185.65%
53	DSM	2.37	0.94	1.22	0.72	0.50	0.00	0.07	-1.43	1.43	152.21%
5050	Ames	2.37	0.63	0.74	0.52	0.22	0.00	0.03	-1.74	1.74	274.62%
285	DSM	2.32	0.34	0.69	0.18	0.51	0.00	0.06	-1.99	1.99	586.17%
5066	Ames	2.29	0.63	0.99	0.40	0.59	0.01	0.07	-1.66	1.66	264.16%
126	DSM	2.29	0.44	0.58	0.31	0.27	0.00	0.04	-1.85	1.85	416.34%
5213	Ames	2.28	0.14	0.18	0.10	0.09	0.00	0.01	-2.15	2.15	1589.94%

[a] The Difference column was calculated by subtracting the 1998 Crashes column from the Mean (expected crash frequency) column.

little or no control have a higher rate than other site categories. This is non-intuitive and should be further examined. The signalized categories are more closely spaced than in Figure 6.12. The reduction due to the inclusion of volume supports the thought that 4-way, signalized sites experience higher volumes and that crash history is negatively affected.

The drill-down procedures shown in the crash frequency section can also be used for crash rates. For example, the signalized intersection groupings could be examined to determine differences and similarities that might indicate potential countermeasures. Also, the little or no control sites could be examined further to discover the source of higher rate expectations.

Covariate effects

Covariate effects were assessed both individually and in combination. This may occur during two different periods (1) during site safety review and alternative consideration or (2) after site improvement for evaluative purposes.

The second of these options, evaluation of predicted impacts, was done during this research. Data were collected for 20 Ames sites that were updated in some fashion. The data were then used as

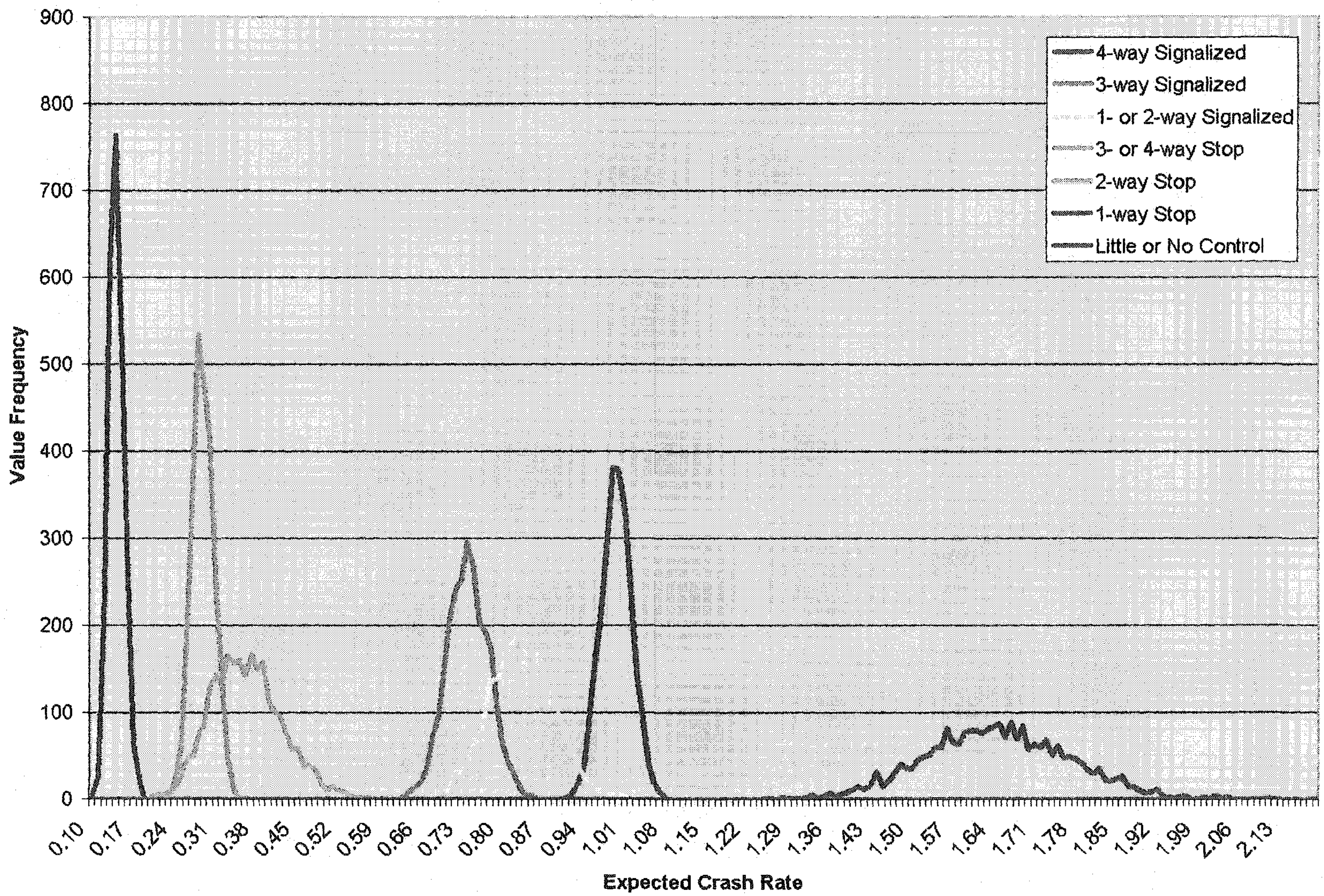


Figure 6.15. Expected rate values—grouped sites densities: controls

covariate dummy variables as was done for the 1031 initial sites. Crash frequencies and crash rates were estimated using the BUGS β values for each covariate. Statistics similar to those calculated for the 1031 sites (of which 20 are shown in Tables 6.8 and 6.9) were then produced for the 20 Ames sites, as displayed in Table 6.10. All of these sites were changed in some manner, ranging from

Table 6.10. Expected crash frequency—updated sites prior to change

ID	1998 crashes	Mean	Maximum	Minimum	Range	Variance	Standard deviation	Difference[a]	Absolute value of difference	% absolute difference
5009	0	0.02	0.04	0.01	0.03	0.00	0.00	0.02	0.02	100.00%
5023	0	0.02	0.04	0.01	0.03	0.00	0.00	0.02	0.02	100.00%
5027	1	0.01	0.02	0.00	0.02	0.00	0.00	-0.99	0.99	9333.96%
5032	1	0.22	0.40	0.12	0.27	0.00	0.04	-0.78	0.78	358.93%
5037	0	0.86	1.14	0.63	0.50	0.01	0.07	0.86	0.86	100.00%
5039	3	0.57	0.86	0.39	0.46	0.00	0.06	**-2.43**	2.43	423.38%
5040	6	0.77	1.05	0.55	0.50	0.00	0.07	**-5.23**	5.23	682.06%
5066	21	5.77	9.07	3.63	5.44	0.45	0.67	**-15.23**	15.23	264.17%
5068	14	17.84	21.08	15.36	5.72	0.65	0.81	3.84	3.84	21.53%
5084	3	8.68	10.19	7.42	2.77	0.21	0.46	5.68	5.68	65.43%
5129	0	0.34	0.50	0.24	0.26	0.00	0.04	0.34	0.34	100.00%
5130	0	0.18	0.26	0.11	0.15	0.00	0.02	0.18	0.18	100.00%
5131	0	0.17	0.26	0.11	0.15	0.00	0.02	0.17	0.17	100.00%
5132	0	0.23	0.33	0.16	0.16	0.00	0.03	0.23	0.23	100.00%
5140	4	13.77	19.49	8.57	10.91	2.54	1.59	9.77	9.77	70.95%
5143	7	1.42	1.87	1.07	0.81	0.01	0.12	**-5.58**	5.58	393.06%
5148	7	14.55	18.45	11.05	7.39	1.07	1.04	7.55	7.55	51.91%
5154	7	9.02	10.70	7.54	3.16	0.24	0.49	2.02	2.02	22.41%
5173	5	2.90	3.77	2.22	1.55	0.06	0.24	**-2.10**	2.10	72.63%
5214	0	1.04	1.44	0.73	0.72	0.01	0.11	1.04	1.04	100.00%

[a] The Difference column was calculated by subtracting the 1998 Crashes column from the Mean (expected crash frequency) column.

addition of a signalization to repaving with a different pavement type. Site 5027 was updated from two-way, stop control to four-way signalization during the intervening period. Site 5066 went from a three-way, signalized intersection to a four-way signalized intersection, in addition to surface type. Sites 5129–5132 and 5140 were only repaved, changing from asphalt cement concrete (ACC) to portland cement concrete (PCC) pavement.

Many of the sites would not have required improvement, if difference between expected and actual crash frequency had been used as a measure. In fact, 15 sites experienced lower than expected crash frequency in 1998 (e.g., the difference was positive) but were updated. These sites were improved for other than safety reasons. For example, several of the sites were along a corridor that was being updated for traffic calming purposes, not necessarily initiated by high crash frequency or rate.

Another two sites (5027 and 5032) experienced greater than expected crash frequency by less than one additional crash (outlined in blue). These sites may have been marginal for requiring safety improvement, as the expected versus actual difference was lower than other sites. The remaining five sites (outlined in red and bolded) had frequencies that were at or above one crash more than expected, most with much more than one crash more than expected. These sites were examined and targeted for improvement.

Table 6.11 shows the expected crash frequency values given the changes in each site along with

Table 6.11. Expected crash frequency—updated sites after change

ID	2001 crashes	Mean	Maximum	Minimum	Range	Variance	Standard deviation	Difference[a]	Absolute value of difference	% absolute difference
5009	0	0.21	0.38	0.10	0.28	0.00	0.04	0.21	0.21	100.00%
5023	1	1.25	2.04	0.75	1.28	0.03	0.18	0.25	0.25	19.92%
5027	3	0.52	0.76	0.35	0.41	0.00	0.06	**-2.48**	2.48	474.38%
5032	0	10.63	21.09	4.78	16.31	5.55	2.36	10.63	10.63	100.00%
5037	0	0.85	1.14	0.63	0.50	0.01	0.07	0.85	0.85	100.00%
5039	0	8.43	12.41	5.77	6.64	0.91	0.96	8.43	8.43	100.00%
5040	3	0.97	1.19	0.77	0.43	0.00	0.06	**-2.03**	2.03	209.73%
5066	17	22.01	26.86	18.36	8.50	1.22	1.10	5.01	5.01	22.78%
5068	7	18.01	21.27	15.50	5.77	0.66	0.81	11.01	11.01	61.12%
5084	1	9.14	10.73	7.81	2.92	0.23	0.48	8.14	8.14	89.06%
5129	0	0.39	0.57	0.27	0.30	0.00	0.05	0.39	0.39	100.00%
5130	0	2.63	3.68	1.89	1.79	0.06	0.25	2.63	2.63	100.00%
5131	0	2.48	3.47	1.78	1.69	0.06	0.24	2.48	2.48	100.00%
5132	0	0.45	0.66	0.32	0.34	0.00	0.05	0.45	0.45	100.00%
5140	6	27.98	40.44	16.99	23.45	10.21	3.20	21.98	21.98	78.56%
5143	4	5.07	7.23	3.47	3.76	0.26	0.51	1.07	1.07	21.08%
5148	6	10.81	15.24	7.96	7.28	1.18	1.08	4.81	4.81	44.52%
5154	7	4.67	7.49	2.48	5.01	0.53	0.73	**-2.33**	2.33	50.00%
5173	5	1.86	2.58	1.38	1.20	0.03	0.17	**-3.14**	3.14	169.03%
5214	0	1.98	2.84	1.39	1.45	0.05	0.22	1.98	1.98	100.00%

[a] The Difference column was calculated by subtracting the 1998 Crashes column from the Mean (expected crash frequency) column.

the actual crash frequencies that occurred during 2001. Notice that now only 4 sites (outlined in red and bolded) have a negative difference, meaning these sites performed worse than expected.

The expected to actual crash frequency difference became worse for site 5027, as shown in Table 6.12, going from –0.99 to –2.48. This might be due the use of only one year of data for both the before and after examination or to the fact that this site has a sparse crash history. The changes to

Table 6.12. Expected crash frequency—updated sites worse than expected

ID	1998 crashes	2001 crashes	1998 mean (expected frequency)	2001 mean (expected frequency)	1998 difference	2001 difference	1998 to 2001 improvement[a]
5027	1	3	0.01	0.52	-0.99	-2.48	-1.49
5040	6	3	0.77	0.97	-5.23	-2.03	3.20
5154	7	7	9.02	4.67	2.02	-2.33	-4.35
5173	5	5	2.90	1.86	-2.10	-3.14	-1.04

[a] The 1998 to 2001 improvement column was calculated by subtracting the 1998 difference column from the 2001 difference column.

the site quite probably influenced the 2001 mean as the site is now compared with sites which experience more crashes on average. However, because the crash frequency increased by two, the difference grew as well.

Similar assessments and statements can be made regarding sites 5040, 5154, and 5173. All three of these sites, with respect to the database, underwent relatively minor changes. The differences in these sites reflect only a change in pavement type and some minor volume adjustments. Sites 5040 (the intersection of Dakota and Lincoln Way in Ames) and 5154 (the intersection of Duff Ave. and 13th St.) underwent more extensive treatment, with additional turn lanes, updated signal mast arms and signal heads, and improved pavement markings added.

Finally, the relatively few crashes at each site, along with the use of only one year of crash history, make the individual site analyses more susceptible to year-to-year fluctuations. For example, if site 5040 had the same number of crashes in 2001 as in 1998, it would have had a –5.03 difference between expected and actual and would have had only a 0.20 gain from 1998 to 2001. However, as shown in Table 6.12, this was not the case. Instead, site 5040 had three fewer crashes in 2001, explaining the more significant gain.

Table 6.13 displays a comparison of all 20 updated sites. For both 1998 and 2001, the actual crash frequency, the expected crash frequency, the differences between expected and actual, and the gain (or loss) in safety are listed for each site. A gain in safety is defined here as the difference between the 2001 expected-to-actual crash frequency difference versus the 1998 difference. This does not equate to a measure of the actual safety of the site. A positive gain equals an increase in safety. Thus, this gain could be used for evaluative purposes.

The majority of sites improved, while 4 (5027, 5148, 5154, and 5173) did not. Site 5027 had two more crashes in 2001, which caused its difference to increase despite an increase in crash frequency expectation. Despite remaining "safe" from the perspective of expected versus actual difference, the site is less "safe" than previously. Site 5148 experienced a similar decline. Site 5154 experienced

Table 6.13. Expected crash frequency—updated sites comparison

ID	1998 crashes	2001 crashes	1998 mean (expected frequency)	2001 mean (expected frequency)	1998 difference	2001 difference	1998 to 2001 improvement[a]
5009	0	0	0.02	0.21	0.02	0.21	0.19
5023	0	1	0.02	1.25	0.02	0.25	0.23
5027	1	3	0.01	0.52	-0.99	-2.48	-1.49
5032	1	0	0.22	10.63	-0.78	10.63	11.41
5037	0	0	0.86	0.85	0.86	0.85	0.00
5039	3	0	0.57	8.43	-2.43	8.43	10.86
5040	6	3	0.77	0.97	-5.23	-2.03	3.20
5066	21	17	5.77	22.01	-15.23	5.01	20.25
5068	14	7	17.84	18.01	3.84	11.01	7.16
5084	3	1	8.68	9.14	5.68	8.14	2.46
5129	0	0	0.34	0.39	0.34	0.39	0.05
5130	0	0	0.18	2.63	0.18	2.63	2.45
5131	0	0	0.17	2.48	0.17	2.48	2.30
5132	0	0	0.23	0.45	0.23	0.45	0.22
5140	4	6	13.77	27.98	9.77	21.98	12.21
5143	7	4	1.42	5.07	-5.58	1.07	6.65
5148	7	6	14.55	10.81	7.55	4.81	-2.74
5154	7	7	9.02	4.67	2.02	-2.33	-4.36
5173	5	5	2.90	1.86	-2.10	-3.14	-1.04
5214	0	0	1.04	1.98	1.04	1.98	0.95

[a] The 1998 to 2001 improvement column was calculated by subtracting the 1998 difference column from the 2001 difference column.

the same crash frequency in both years but the traffic volume decreased from 22,290 to 20,000 daily entering vehicles (DEV). Similarly, site 5173 had the same crash frequency in both years but the traffic volume decreased from 18,803 to 17,300 DEV. The volume change could explain the loss.

Many of the sites experienced a decrease in crashes from 1998 to 2001 (5040, 5066, 5068, 5084, 5143, and 5148). Some of these declines were more significant than others. The improvements at these sites should be examined to assess their potential for reducing crash history at other sites.

For example, site 5066 (the intersection of Lincoln Way and Grand Ave in Ames) was updated from essentially three-way, signalized operation to four-way, signalized operation. This changed the sites to which site 5066 was compared and increased the expected crashes, as four-way, signalized intersections tend to experience more crashes than three-way, signalized intersections. Most of the gain at site 5066 is due to the significant increase in expected frequency. Two further observations can be made. First, site 5066 experienced four fewer crashes in 2001 than in 1998 and, from a brief examination of preliminary 2003 data, site 5066 had only experienced 3 crashes through August. Second, site 5066 should probably have been considered a four-way, signalized intersection in the initial analysis. The site has always had four approaches but the south approach (e.g., northbound) was formerly only an entrance to the Iowa DOT offices in Ames. The south approach now serves both the Iowa DOT and a significant shopping center and has multiple lanes.

Rankings

The Bayesian method output can also be used to calculate rankings. These results are network screening rather than prioritization rankings. Network screening rankings are used to determine which sites should be reviewed. Prioritization rankings are completed after sites have been further reviewed, countermeasures have been determined, and an economic analysis has been conducted. Network screening directly affects the input to prioritization ranking by determining which sites will be further analyzed for countermeasures and subsequent economic appraisal.

Table 6.14 includes 20 of the 1031 sites, demonstrating six ranking schemas:

Table 6.14. Ranking—frequency and rate

	Rank						
ID	Actual frequency	Actual rate	Bayesian expected frequency	Bayesian expected rate	Difference in frequency	Difference in rate	Frequency difference
5020	4	9	247	507	1	7	-17.45
97	3	38	153	467	2	45	-15.85
5066	5	18	166	411	3	22	-15.23
140	8	86	154	511	4	70	-14.89
85	15	73	223	535	5	49	-14.77
257	12	8	191	366	6	14	-13.94
98	13	21	170	376	7	25	-13.31
5172	35	2	343	486	8	2	-13.07
22	31	83	272	577	9	51	-12.84
160	26	22	259	488	10	18	-12.62
45	17	14	150	260	11	26	-11.70
177	2	40	47	236	12	87	-11.68
178	7	64	73	314	13	82	-11.61
54	46	114	310	633	14	65	-11.51
2	20	118	127	485	15	100	-11.16
11	1	62	27	237	16	110	-10.93
117	6	49	61	253	17	89	-10.46
1332	70	25	529	755	18	11	-10.36
93	11	6	91	106	19	27	-10.33
26	22	11	123	209	20	32	-10.12

Note: Grey shaded columns correspond to frequency-based rankings and blue shaded columns correspond to rate-based rankings.

- 1998 crash frequency (i.e., actual frequency rank),
- 1998 crash rate (i.e., actual rate rank),

- Bayesian method expected frequency,
- Bayesian method expected rate,
- Difference between the expected and the actual frequency, and
- Difference between the expected rate and the actual rate.

The table also lists the actual frequency difference or potential for improvement. The table is sorted by difference in frequency rank, which is the difference between the expected value of frequency, as determined using the Bayesian methodology, and the actual 1998 crash frequency.

Figure 6.16 displays the densities of expected crash frequency for each of the top 20 sites listed in Table 6.14. Sites that have a higher expected crash frequency are visually discernible. Sites with higher expected crash frequencies, over their entire distribution, can quickly be singled out and groupings within the top 20 sites can be constructed. For example, the five sites with the highest expected crash frequencies can be grouped together. When grouping, the amount of overlap between site densities should be considered. Significant overlap indicates less certainty between rankings for sites. For example, one site might be ranked fifth and another sixth but, if significant overlap is present, these two sites are more similar than these rankings indicate. Sites with similar distributions might be more correctly assigned rankings that indicate differences in safety performance.

Figure 6.16 displays nothing regarding the distribution of the expected versus actual crash frequency difference. It only displays what is expected at the site. Therefore, nothing is learned about the potential for safety improvement for each site. However, it does display the expected ranks for the sites, if each site were performing as expected.

Ranking of frequency difference is promoted by several researchers (Hauer 1986,1996; Hauer et al. 1986,1988,2002; Hauer and Persaud 1984; ITE 1999). This method is used by the federal safety design software called the Interactive Highway Safety Design Model (IHSDM) and will be used by the federal safety assessment software SafetyAnalyst currently under development.

For these 20 sites, the separate ranking methods have produced no real similarity. Sites ranked high for one method are not ranked high in other methods. The order within each ranking list is not maintained. This is true throughout all 1031 sites. Each ranking method has different bases and thus its interpretation must be unique.

Actual frequency and rate have historically been used by many agencies for rank lists. Many still rely on these methods, likely due to the ease of calculation. A perception may exist that sites with high frequencies or rates should be improved. However, as clarified by several researchers, this is not

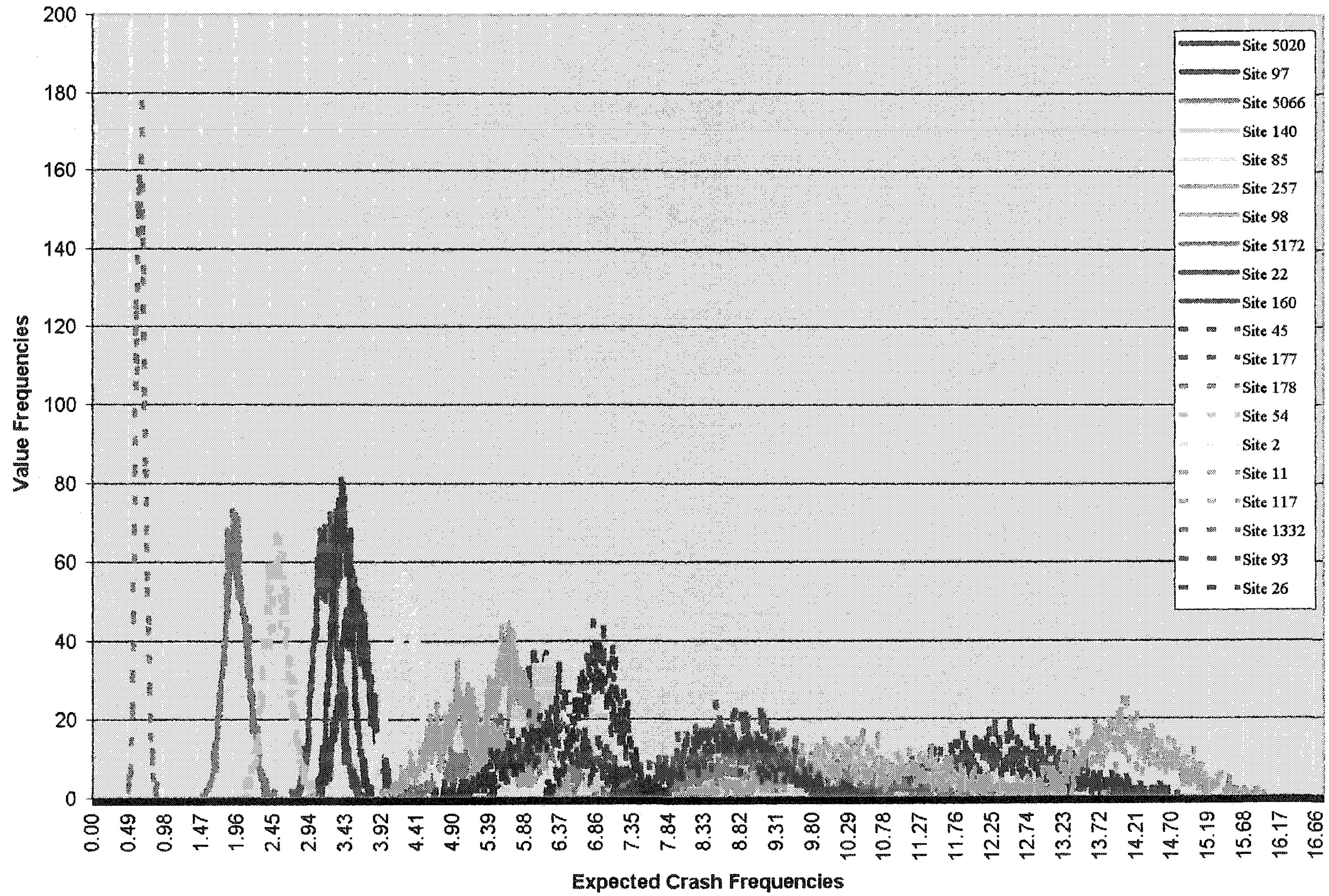


Figure 6.16. Ranking—top 20 site densities

necessarily the case. Some factor inherent to certain sites, such as volume, may cause a higher frequency or rate. Both methods have deficiencies (e.g., lack of volume consideration or a non-linear volume-to-crash relationship), which some have attempted to minimize using a combined ranking.

Expected crash frequency and expected crash rate should not be used as ranking mechanisms. The values are baselines for measuring actual occurrence and can be used to gain insight into how a site is performing. The difference between the expected value and the actual value provides this insight. Rankings based on the difference are more informative because sites performing worse than expected can be determined and targeted. While high frequency might suggest lack of safety, closer examination quite frequently finds high volume to blame. Control of volume is beyond the purview of the safety community. However, the difference identifies sites with problems beyond high volume.

Some ranking methods include severity as a measure, including the methods used in Iowa. Table 6.15 displays ranks for the same 20 sites previously listed, sorted in the same fashion (i.e., by crash

Table 6.15. Ranking—severity methods

	Rank			
ID	Pre-2003 Iowa method	Post-2003 Iowa method	Expected frequency and rate with pre-2003 severity	Expected frequency and rate with post-2003 severity
5020	1	1	179	90
97	9	17	145	88
5066	27	56	164	130
140	13	12	157	82
85	36	31	228	121
257	19	42	147	102
98	3	3	114	50
5172	30	55	262	181
22	17	11	229	103
160	24	24	220	116
45	2	2	70	24
177	25	47	61	58
178	12	14	71	36
54	88	113	317	244
2	31	23	135	76
11	8	7	28	9
117	15	21	58	30
1332	14	16	410	217
93	5	6	17	6
26	4	4	49	17

Note: The grey shaded columns correspond to the pre-2003 Iowa ranking method and the blue shaded columns correspond to the post-2003 Iowa ranking method. The values outlined in blue indicate high correspondence between pre- and post-2003 Iowa method rankings for those sites. The values outlined in red indicate the same but with use of Bayesian expected frequencies and rates.

frequency difference), but with rankings using the severity methods listed.

The Bayesian expected frequency and expected rate were combined with the severity scores for each method. This was done using the same summation scheme as for each method. However, it should be noted that this method is questionable. Severity probably should be included in the model instead.

In Table 6.15 just as in Table 6.14, the rankings are not very similar. The two different Iowa methods are relatively close, with many matching site ranks, but bear little relation to the expected value plus severity methods. Comparing the Iowa method rankings to the frequency difference rankings in Table 6.14, similarity is limited, with some but not all of the top 20 sites for one being also ranked in the top 20 for the other.

Table 6.16 displays the values for the top 20 sites determined by averaging ranks over the 2500

Table 6.16. Draw-based rankings—averages

ID	Mean	Rounded Mean	Standard Deviation	Minimum Rank	Maximum Rank	Final Rank	Previous Rank
5020	1.00	1	0.00	1	1	1	1
97	2.20	2	0.41	2	4	2	2
5066	3.43	3	1.19	2	11	3	3
140	4.12	4	0.91	2	7	4	4
85	4.47	4	0.61	3	6	5	5
257	6.04	6	0.92	2	12	6	6
98	7.19	7	0.86	5	12	7	7
5172	8.13	8	0.77	7	12	8	8
22	9.08	9	0.75	6	12	9	9
160	10.40	10	0.71	8	13	10	10
45	12.96	13	2.29	7	31	11	11
177	13.04	13	3.16	6	32	12	12
54	13.16	13	1.11	11	17	**13**	**14**
178	13.43	13	4.20	4	42	**14**	**13**
2	14.92	15	1.33	11	22	15	15
11	15.84	16	2.47	9	26	16	16
1332	17.96	18	1.20	13	21	**17**	**18**
93	18.69	19	3.45	11	39	**18**	**19**
117	18.76	19	5.82	6	51	**19**	**17**
26	19.26	19	1.63	14	27	20	20

Note: The grey shaded column shows the draw-based rankings and the blue shaded column shows the rank determined based on difference between expected and actual from Table 6.14. The red outlines define sites that have exchanged rankings.

Gibbs sampling (e.g., BUGS) draws. Because 2500 sample draws came from the Bayesian analysis, each site has 2500 values for expected frequency and rate, and 2500 expected versus actual differences can be calculated. Using these differences, each site can be ranked on the individual draws, producing 2500 rank values for each site. Finally, mean ranks, standard deviations, minimum ranks, and maximum ranks can be calculated and, since the mean rank is a measure of the average rank and not an actual rank, a final rank can be assigned.

Table 6.16 lists the same 20 sites as determined previously. However, the sites rankings vary somewhat, especially in the lower ranks. For example, the first 12 sites are ranked the same in both lists, with site 5020 ranked first. Sites 54 and 178 swap rankings and sites 93, 117, and 1332 also exchange rankings.

The mean provides an initial indication of how much worse one site is than another. Notice that the sites that have changed rankings have similar means. The standard deviations support this variability in rank values. Sites with larger standard deviations within each change group have been ranked lower. The minimum and maximum ranks further strengthen this conclusion. The sites that have declined in ranking have wider difference between maximum and minimum, with both a lower minimum and a higher maximum than the other sites grouped with them.

Figure 6.17 shows the distributions of the draw-based rankings. Clearly, site 5020 (represented by the red point (at relative position rankings=1, value frequencies=2500) is ranked first, as its distribution is centered at 1 and its spread is non-existent. Site 97 has a large frequency of rank 2 and rank 3 and is definitely more often ranked higher than site 5066. Site 5066 appears higher ranked than sites 85 and 140, but the distinction is not as clear as the distributions overlap much more. Sites 85 and 140 are more intertwined. These sites are most definitely ranked 3, 4, and 5 as the next group of sites is discernibly lower. Sites 257, 98, 5172, 22, and 160 round out the top 10 with fairly clear distinctions.

Similar statements can be made about sites ranked 11 through 20, though the distinctions appear less certain. For example, the distributions for sites 45 and 177 are virtually indistinguishable. This is supported in Table 6.16 as the means for these sites are similar but site 177 has a larger mean and a greater standard deviation. The distributions for sites 1332, 93, and 117 overlap markedly, supporting the uncertainty displayed in their rankings between the two methods.

Another way of displaying the relative ranks is by displaying percentages for each rank value for each site, as shown in Table 6.17. Clearly, site 5020 is ranked first and site 97 is ranked second. Both have the preponderance of rank values for those two rankings, respectively.

Sites 5066, 140, 85, and 257 (shaded in purple) are more closely distributed. However, two clues

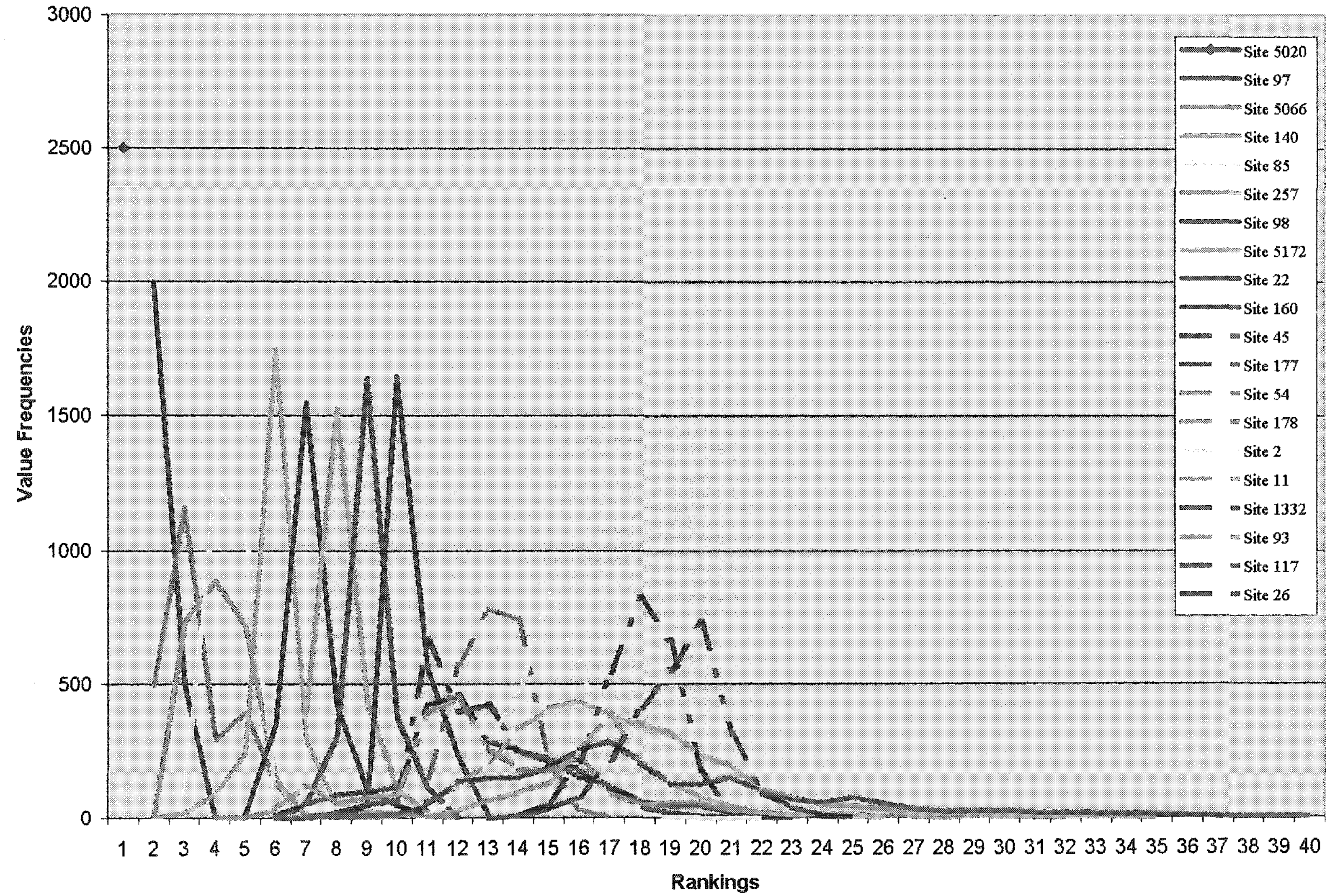


Figure 6.17. Draw-based rankings—distributions

Table 6.17. Draw-based rankings—percentages

	Site																			
Rank	**5020**	**97**	**5066**	**140**	**85**	**257**	**98**	**5172**	**22**	**160**	**45**	**177**	**54**	**178**	**2**	**11**	**1332**	**93**	**117**	**26**
1	**100**																			
2		**80**	20	0		0														
3		20	**46**	29	4	1														
4		0	12	**36**	**49**	4								0						
5			16	29	45	10	0							0						
6			5	6	3	**70**	14		0			1		1					0	
7			0	0		11	**62**	16	2		0	2		5					0	
8			0			2	17	**61**	12	0	1	4		2					1	
9			0			1	4	17	**66**	2	2	4		3		0			0	
10						1	2	4	15	**66**	3	5		4		0			1	
11			0			0	1	1	5	22	**27**	17	6	16	0	3		0	2	
12						0	0	0	0	9	16	**18**	23	**18**	3	5		1	6	
13										0	17	12	**31**	10	12	8	0	3	6	
14											10	10	30	7	18	13	0	4	6	0
15											9	8	8	7	**33**	17	2	5	8	1
16											7	6	1	9	23	**18**	8	11	10	3
17											5	5	0	4	8	16	22	**15**	**12**	9
18											2	3		2	1	8	**33**	14	8	16
19											1	2		2	0	5	27	13	5	22
20											0	2		2	0	3	7	10	5	**29**
21											0	1		1	0	2	1	8	6	13
22											0	0		1	0	1		4	4	4
23											0	0		0		1		3	3	2
24												0		1		1		2	2	1
25												0		1		0		2	3	0
26												0		0		0		1	2	
27														0				0	1	0
28														0				1	1	
29														0				1	1	
30														0				0	1	
31											0	0		0				0	1	
32												0		0				0	1	
33														0				0	1	
34														0					1	
35														0				0	1	
36																			0	
37																			0	
38																			0	
39																		0	0	
40																			0	

Note: The bold, red numbers indicate ranking values modes for each site. The shading groups sites with similar rank distributions.

aid discernment. First, the bold, red values indicate the modes of the ranking values for the sites. The ranking value modes generally increase as the sites increase in rank value. Second, the cumulative percentage of rank values favors the sites in the order of final ranking.

The same observations can be made for other groupings. Sites 98, 5172, 22, and 160 (shaded in light yellow) follow this same pattern and match the order shown in Figure 6.17. Sites 45 and 177 (shaded in light grey) are again virtually indistinguishable except that the median ranking value is slightly higher for site 45 than for site 177. Similar observations can be made regarding sites 2 and 11 (shaded in light orange) but sites 1332, 93, and 117 (shaded in light blue) must be interpreted differently. Though the ranking value mode for site 1332 is higher than for sites 93 and 117, its rank is lower. Notice that the percentage of ranking value for site 1332 at the same position as the ranking value modes for sites 93 and 177 (rank = 17) is higher than the percentages for those two sites. Thus, despite having a higher mode, site 1332 is ranked lower more frequently.

Reliable validation of the best ranking method would be difficult. Proper site safety assessment can only be accomplished by visiting sites and by observing traffic behavior. Several practical difficulties prevent this. First, visiting every site in most rankings would be extremely time-consuming. Second, the assessments almost certainly would involve some subjectivity. Individual assessments would then have to be compiled and compared to the rank provided by each method. Also, site assessments would contain no indication of expectations for the site. The response would be to target high frequency or rate sites, without regard for safety improvement potential. However, theoretical considerations favor Bayesian methods.

Predictions

Bayesian analysis can be used to predict safety performance. The expected values, from Tables 6.8 and 6.9, are estimates of the crash frequencies and crash rates that would be expected at each site if nothing were changed. Expected value analysis is one method of prediction. Adjusting covariates leads to predictive results. As shown by the different values for expected crash frequency between Table 6.10 and Table 6.11, covariate values affect the expectation for each site. The covariate values can be adjusted during pre-design, and a predictive crash frequency or rate may be calculated, facilitating safety-based planning. Adjustments may also be made to the volume, accounting for natural traffic growth over time as is often done in transportation planning models. Predictions of expected crash frequency or rate can be calculated using these updated volumes. The probabilities inherent in the distributions and the β values, correctly interpreted, help indicate which variables might be more likely to reduce crash experience at a site. Using these, determinations of appropriate countermeasures might be made that lead to safety improvement. The predicted values lead to ranking lists of potential safety for sites and estimated impacts of the changes in safety at those sites.

Exploratory study of BUGS results

The results for the frequency values from the exploratory study of the BUGS results are shown in Table 6.18. The results show that, for these 10 sites, there is essentially no difference between the expected value of the crash frequency between the various sample sizes or between the separate chains run in the final model. The only substantial gain from using 2500 draws rather than 625 draws or 50 draws is that a larger sample size increases the confidence in the results, as shown by the standard deviations listed in Table 6.19. Comparing the standard deviation for 2500 draws with the

Table 6.18. Exploratory BUGS results—frequencies

		2500 draws	625 draws				50 draws			
ID	1998 crashes	Mean	Chain 1 mean	Chain 2 mean	Chain 3 mean	Chain 4 mean	Chain 1 mean	Chain 2 mean	Chain 3 mean	Chain 4 mean
11	25	14.9	14.8	14.9	14.9	14.8	14.8	14.9	14.9	14.9
177	24	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
97	22	14.0	14.0	14.1	14.0	14.0	14.0	14.2	13.9	14.0
117	21	15.1	15.2	15.0	15.1	15.0	15.2	14.9	15.3	14.9
140	21	13.6	13.6	13.7	13.6	13.6	13.6	13.7	13.6	13.8
178	21	9.1	9.1	9.0	9.1	9.1	9.2	8.9	9.2	9.0
5020	21	9.2	9.2	9.2	9.2	9.2	9.2	9.3	9.3	9.2
5066	21	12.9	12.9	13.0	12.9	12.8	12.9	13.0	12.6	12.7
10	20	18.9	18.9	19.0	19.0	18.9	18.9	19.0	18.9	18.8
121	20	17.3	17.2	17.3	17.3	17.2	17.2	17.3	17.2	17.1

Table 6.19. Exploratory BUGS results—frequency standard deviations

		625 draws				50 draws			
ID	2500 draws	Chain 1	Chain 2	Chain 3	Chain 4	Chain 1	Chain 2	Chain 3	Chain 4
11	0.6492	0.6209	0.6343	0.6516	0.6861	0.6150	0.5924	0.6336	0.5888
177	0.6775	0.6779	0.6698	0.6696	0.6927	0.6623	0.7015	0.6490	0.7365
97	0.8064	0.8090	0.7740	0.8216	0.8193	0.7168	0.7933	0.8412	0.8485
117	1.6068	1.6204	1.5708	1.5945	1.6380	1.2347	1.6255	1.7094	1.7462
140	0.7496	0.7204	0.7343	0.7800	0.7612	0.6635	0.7325	0.7344	0.9080
178	1.0817	1.0563	1.0541	1.1228	1.0917	0.8964	1.0243	1.2445	1.0980
5020	0.4975	0.4892	0.4848	0.5044	0.5093	0.4222	0.4357	0.5075	0.4216
5066	1.4479	1.4317	1.5142	1.4415	1.4023	1.3829	1.5334	1.3649	1.4002
10	0.9767	0.9740	0.9641	0.9416	1.0241	0.8689	0.9003	0.9111	0.9332
121	0.8898	0.8873	0.8783	0.8578	0.9329	0.7915	0.8201	0.8300	0.8501

standard deviations for each chain for 625 draws and 50 draws, the 2500 draw standard deviation appears to be a rough average of the values from the chains. The standard deviations for each chain in the 625-draw option, when compared with the standard deviations from the 50-draw option, appear more stable. That is, there is less variation between chains and the values are closer to the 2500 draw value. Additional draws seem to improve and stabilize model results, with chain-to-chain differences lessened.

It should be noted that the draws from each of the chains for the 625-draw option were used to construct the 2500-draw sample and the 50-draw option draws are a sample drawn from the 625-draw option. In addition, all of these draws were obtained after model convergence was achieved (i.e., after 5000 iterations of the model were completed). Theoretically, the values drawn should represent draws from the same model and the values should be essentially indistinguishable.

Recall, also, that the variance is the square of the standard deviation. Thus, the better the standard deviation, the better the variance and the higher the confidence in the expected value. Sites with lower variances have less uncertainty and sites with higher variances have more uncertainty. Most likely, sites with less certainty are those with fewer sites to pool with.

Similar results for the rates values from the exploratory study of the BUGS results are shown in Table 6.20. The table displays results that lead to a similar conclusion as that for the frequencies,

Table 6.20. Exploratory BUGS results—rates

		2500 draws	625 draws				50 draws			
ID	1998 rate	Mean	Chain 1 mean	Chain 2 mean	Chain 3 mean	Chain 4 mean	Chain 1 mean	Chain 2 mean	Chain 3 mean	Chain 4 mean
5160	3.96	0.11	0.10	0.12	0.10	0.11	0.10	0.08	0.07	0.06
5172	3.71	1.44	1.44	1.44	1.44	1.45	1.45	1.46	1.45	1.46
1695	3.21	0.35	0.36	0.35	0.35	0.35	0.36	0.34	0.35	0.35
2014	3.05	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
5162	2.91	0.43	0.42	0.42	0.44	0.44	0.48	0.41	0.39	0.37
93	2.82	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.21	1.19
282	2.81	0.53	0.53	0.52	0.53	0.53	0.53	0.52	0.53	0.54
257	2.62	1.04	1.04	1.03	1.03	1.04	1.05	1.04	1.04	1.05
5020	2.60	1.14	1.13	1.14	1.14	1.14	1.14	1.15	1.15	1.14
5124	2.58	0.43	0.42	0.42	0.44	0.44	0.48	0.41	0.39	0.37

namely, that the various sample sizes achieve similar means and the variations in expected values between chains are minimal. As shown in Table 6.21, the standard deviation values for the 2500 draws seem to be a rough average of the chain standard deviations, with the 625-draw option chains displaying less variability between chains than the 50-draw option chains. The 625-draw option

Table 6.21. Exploratory BUGS results—rate standard deviations

ID	2500 draws	625 draws				50 draws			
		Chain 1	Chain 2	Chain 3	Chain 4	Chain 1	Chain 2	Chain 3	Chain 4
5160	0.0410	0.0355	0.0420	0.0357	0.0471	0.0258	0.0242	0.0325	0.0405
5172	0.1133	0.1159	0.1083	0.1155	0.1132	0.1016	0.1267	0.1166	0.1011
1695	0.0543	0.0545	0.0532	0.0547	0.0544	0.0447	0.0516	0.0617	0.0430
2014	0.0706	0.0683	0.0719	0.0712	0.0713	0.0667	0.0718	0.0878	0.0820
5162	0.3052	0.2870	0.3026	0.3193	0.3112	0.3437	0.2978	0.2591	0.3225
93	0.0896	0.0880	0.0918	0.0896	0.0891	0.0914	0.1021	0.1003	0.0757
282	0.0591	0.0578	0.0588	0.0592	0.0607	0.0532	0.0551	0.0628	0.0657
257	0.0975	0.0925	0.0952	0.1000	0.1015	0.0706	0.1010	0.0907	0.1002
5020	0.0616	0.0606	0.0600	0.0625	0.0631	0.0523	0.0540	0.0628	0.0522
5124	0.3052	0.2870	0.3026	0.3193	0.3112	0.3437	0.2978	0.2591	0.3225

standard deviations are also much closer in value to the 2500 draw standard deviations.

These results indicate that though the values should theoretically be the same no matter the size of the sample, an increase in the number of draws should not be harmful. In fact, increased sample size seems beneficial overall, both in refinement of the mean and standard deviation and development of smoother density diagrams. Therefore, as obtaining additional draws poses no significant difficulties, only computer resources, it is recommended that analysts draw as many as might reasonably be drawn.

CHAPTER 7. SUMMARY AND RECOMMENDATIONS

Within this research, the traffic safety problem was defined, its history briefly reviewed, and potential for improvement was identified. A hierarchical Bayesian methodology was applied and implemented in an Iowa case study. In the following, a summary of the potential application of hierarchical Bayes for the purpose of network screening is described. Finally, recommendations for future application and policy implications resulting from its use are discussed.

Summary

Bayesian methods for the purpose of network screening are superior to classical statistical methods for several reasons. First, classical methods that have been used for network screening have not directly accounted for RTM, which may result in incorrect final rankings. Second, past methods have only directly considered crash history and not site characteristics. Third, classical methods provide no simple mechanism for inclusion of past ranking knowledge or for assessing the impact of site characteristic changes. Fourth, classical methods only provide a point estimate of the ranking or crash frequency. This provides little ability to compare how much worse one site is than another.

Bayesian methods provide a measure of expectancy for sites, rather than relying on crash history. By using both site characteristics and crash history as part of the database, Bayesian methods group similar sites and smooth the random fluctuation due to RTM. EB methods accomplish this by using a priori site categorizations. Hierarchical Bayesian methods categorize within the process. By obtaining site expected values and comparing these to actual crash history, an analyst can determine how one site compares to another and whether the site is over- or under-represented in terms of crash frequency or rate.

Site comparability can be achieved through use of the expected value (i.e., the mean) and the accompanying uncertainty (i.e., the variance). With these tools, not only can an analyst determine that one site is worse than another on average but also the level of confidence in this assessment. For example, if one site had a greater mean but the site distribution overlapped considerably with another site, it would be difficult to separate the sites. However, if no overlap were present, the two sites could be said to be significantly different. Standard hypothesis tests can be applied.

Over-represented sites are those that leading researchers refer to as “sites with promise (SWiPs).” These sites demand some response for two reasons. First, they are experiencing a greater crash history than would be expected given their characteristics. That is, they are unsafe. Second, they are sites whose potential for mitigation is most likely to provide the most return on investment.

However, this is not guaranteed and it is possible that some over-represented sites will cost more to improve than the benefit that can be gained.

Under-represented sites are those that are performing much better than expected. These sites should be carefully reviewed and compared to poorly performing sites. The assessment should attempt to determine what characteristics of the sites cause them to perform better than expected. The information gained could be used to improve design practices and avoid future problem sites.

Bayesian methods also provide a measure of uncertainty (i.e., variance) in site rankings. The variance provides a measure of confidence in each site's ranking. The distributions for each site's ranking can be compared with other sites to assess the degree of overlap and certainty in the rankings. Additionally, sites with similar ranking distributions can be grouped and, if natural cutoff points are evident, higher rank groupings can be addressed prior to lower rank groupings.

Classical methods, on the other hand, only provide a rank, a mean of the past crash frequencies, and an overall variance for the analysis. From this variance, maximum and minimum rank values can be assessed, as shown in Table 7.1. Looking at the site ranked first in Table 7.1, it is evident that if

Table 7.1. Classical method site ranks

Rank	Mean	Maximum[1]	Minimum[1]
1	4.0	5.0	3.0
2	3.8	4.8	2.8
3	3.6	4.6	2.6
4	3.5	4.5	2.5
5	2.9	3.9	1.9
6	2.8	3.8	1.8
7	2.7	3.7	1.7
8	1.5	2.5	0.5
9	1.3	2.3	0.3
10	1.0	2.0	0.0

[1] Assuming a group variance of 1.

this site were assigned its minimum rank, then it could be ranked as low as eighth. Similar statements could be made with regard to all the sites. Other than the mean, there is still little identification of how much worse one site is than another. A measure of uncertainty in the rank values would provide for an assessment of whether sites one through four were fairly similar (e.g., due to possibly similar means) or whether 100 percent confidence could be placed in the first place ranking.

Essentially, the discussion of uncertainty distills into a discussion of credible sets. Credible sets are the Bayesian equivalent to classical confidence intervals. They provide an idea of the level of uncertainty in a value. Bayesian analyses provide credible sets for individual sites for each result, whether βs, expected values, covariate effects, rankings, or predictions. Classical methods can provide measures of uncertainty for the βs (e.g., GENMOD results), but only means and overall analysis confidence intervals for the crash history and rankings. The advantage for Bayesian methods is that an analyst now has both a measure of over- or under-representation and a measure of confidence in this. Also, an analyst can adjust certain characteristics to assess their effect on expectations and again obtains a measure of uncertainty.

Another Bayesian advantage over classical methods is the ability to use past analysis results as part of the prior information for future analyses. For example, past results for βs can be utilized as prior knowledge for further analyses on another set of sites. The mean and variance for each β can be input into the model as prior information. The variance can be adjusted (i.e., increased) if the analysis has been altered or there is reason to believe the sites are different. This adjustment of the variance simply causes the model to rely more on the data than on the prior values. Examples of analyses that can utilize past β values include:

- Analysis of intersections in another city or set of sites (e.g., Cedar Rapids and Iowa City),
- Regional application of the model (e.g., comparability to intersections in different cities),
- Statewide application of the model, including segments and intersections, or
- New models that do not include intersections (e.g., citywide comparability) but use one of the current covariates (e.g., land use).

All of these examples would require an increase in the variance, especially the last example where sites are no longer included. However, once analyses of each type are done, the βs resulting from the analyses could be used for similar such analyses.

Both EB and hierarchical Bayesian methods are an improvement on classical SICL methods. Both can provide the advantages and improvements described above. Traffic safety applications of EB have been under development for a couple decades, whereas hierarchical Bayes has only been explored recently.

However, hierarchical Bayes improves on EB. EB requires a priori categorization of sites while hierarchical Bayes does not. First, the categorization process can become complex, partially due to the fact that the categories must be defined. Second, EB requires specification of estimated values for the hyperparameters, typically referred to as SPFs. The values must be determined prior to EB application and must be determined for each defined category. This determination requires numerous sites of each category and subsequent analyses. Thus, though EB requires no more data for the final analysis than hierarchical Bayes, calculation of SPFs requires significant additional data and analysis resources. Fortunately, both EB and hierarchical Bayes can utilize previously determined SPFs for future analyses. EB requires periodic calibration of the SPFs, while hierarchical Bayes does not.

Limitations

Despite the many potential advantages hierarchical Bayesian methods provide, the present model has several limitations that prevent statewide application. First, a statewide model for SICL list development should include both intersections and segments. This would require additional variables as the present model primarily considers intersection-specific characteristics. Also, the problem of the artificial β limit imposed by the software would need to be resolved. Second, assumptions (e.g., dropping the error term) made during development of the present, two city model are not valid for a multiple city model. Third, the present model does not include spatial and temporal effects. Spatial effects help in assessment of the impacts of site proximity and regional differences. Temporal effects account for year-to-year fluctuations in data. Fourth, the visualization of results is limited. Clear visual displays (e.g., tables, charts, maps) help analysts determine deficiencies more quickly and confidently. Fifth, the present methodology is only partially automated. Application of this method on the current scale (i.e., two cities with 1031 sites) is barely manageable. Wider application would prove overwhelming. Finally, the current model contains no measure of severity. Many classical SICL methods include severity, which is often a topic of interest to policymakers, decision-makers, and the public.

Recommendations

Due to limitations and other potential applications, several recommendations can be made. Recommendation categories include model extension, software improvements or replacement, data improvement and accessibility, evaluation of critical data, and further applications.

Many extensions to the model have been previously listed. Regional (e.g., statewide, county-wide, citywide) application of the model is required for ranking of candidate locations. Without regional application, agencies cannot effectively assess which sites should be targeted for potential mitigation. Therefore, the model updates required for regional application should be researched and incorporated. These updates include consideration of intersection and segments, reconsideration of model assumptions, and inclusion of spatial and temporal effects.

Because severity is often of concern, severity should be incorporated into the process at some point. This may not occur during network screening but during economic appraisal. However, many agencies would prefer to target their efforts prior to economic appraisal.

Automation must be improved. The lack of automation is partially due to the variety of software used (e.g., ArcView, SAS, BUGS, Excel). To automate the methodology, either connections between the software must be developed, consolidation of processes into fewer software platforms must be done, or development of new software must occur.

The artificial β constraint imposed by the BUGS software must be addressed. Creation of a regional model that includes intersections and segments will most likely require additional variables. The β constraint obviously limits the number of variables that may be included. Therefore, a method must be developed that either separates the analyses and allows later combination or allows inclusion of all variables. Both are possible but the latter may be more desirable because it avoids a priori categorization and it allows all sites to be considered simultaneously in the Bayesian analysis. Development of new software for increased automation could address the β constraint.

While investigating the β constraint, the number of draws or iterations required for effective results should be examined. Increasing the number of draws has several advantages, including smoother distribution curves, increased confidence in results, more potential variability. This may be offset by increased computation time, which may be addressed by continued computer improvements, fewer iterations, or improved software. It is not clear which approach is most advisable.

Visualization of results could be improved for increased analyst comprehension. Both the appearance and production of tables, charts, and maps could be improved. Tables and charts that more effectively present similarities and differences between sites and site groupings could be developed. Also, table and charts that present the results differently might provide insight not currently gained. Maps could communicate proximity and connectivity between sites. For example, an analyst might not immediately realize that two highly ranked sites are along the same corridor or that several highly ranked sites are along a corridor. An easily interpretable map would communicate this very effectively.

Production of tables, charts, and maps is again not automated. The creation of these visual displays can be tedious, limiting the number of displays created or increasing time involved in production. Along with other automation efforts, it would be advisable to automate display creation. Initial efforts might focus on development of templates. Future efforts could create displays as needed.

Approach-based data and analyses should be incorporated at some point. Analysis of intersections on an approach basis identifies movements that are performing worse than would be expected. A result of an approach-based analysis might be addition of left-turn bays and a protected phase for left-turning traffic. Identification of approaches needing mitigation may be done during, after, or separate from regional network screening. The timing depends on the model form. Performing approach-based analyses during regional network screening includes the approaches in the overall ranking of sites. Separate approach-based analyses would not. Approach-based analyses after regional network screening would presumably only be done on highly ranked intersections, identifying approaches of more concern within these intersections. While less data-intensive than an overall approach-based analysis, there may be approaches that are performing significantly worse than expected at intersections that are, as a whole, performing too poorly.

Network screening is only the first step in the resource allocation process. Other steps included in resource allocation include diagnostic review and countermeasure identification, economic appraisal and priority ranking, and evaluation (MRI 2002a,b,c,d,e,f,g,2003a,b,c,d,e). Network screening merely identifies sites that justify further review. Sites with similar likely crash reductions may have very different opportunities for improvement. For example, one may cost significantly more to mitigate than the other. For final assignment of resources, first potential countermeasures for sites must be proposed. Then, these countermeasures must be assessed for their benefits and ranked according to the most return on investment. The countermeasure projects ranked highly based on return on investment are then carried out. Later, evaluation of the actual impact should occur.

Data improvement and accessibility efforts are critical to further application of the Bayesian model. Improved roadway characteristic data, both segment- and intersection-based, is critical for input into the model. Site visits cannot be made to collect all the data on a regional scale. Therefore, a regional database would greatly enhance the model and increase its scope. In Iowa, for example, the current roadway database is undergoing a redesign process. As part of this, personnel within the Iowa DOT Office of Transportation Data are considering the inclusion of intersection characteristics.

Without access to data, data do no good. Therefore, data accessibility and connectivity efforts are also critical to further application of the Bayesian model. For transportation data, linear representations of the data can be used to connect data and facilitate access to all types of data, including roadway, crash, bridge, pavement, maintenance, and construction. In Iowa, for example, a current linear referencing system (LRS) effort is underway. The LRS project has several different linear referencing methods (LRMs) available. These LRMs allow users to access data using the LRM they are most familiar with. Thus, in Iowa, access is improving.

Related to data improvement and accessibility efforts is the value of data for use in safety analyses. Not all data has tangible benefits to all purposes. For development of SICL lists, some data are useful, some are redundant, and some are useless. While considering data improvement efforts, it is appropriate to weigh the benefit of data against the cost of collecting, storing, and maintaining the data. For example, given the equation

$$y = ax_1 + bx_2 + cx_3,$$

where y is the expected crash frequency, x_1, x_2, and x_3 are intersection characteristics, and a, b, and c are the respective slopes, an analysis of the impact of the inclusion of each characteristic can be done. With all variables included, the rankings for five sites might be as shown in the Rank (all) column of Table 7.2. However, if the x_3 variable were discarded, the rankings might be as shown in the Rank (x_1 and x_2) column. Mitigating the first three sites in each list might cost $7 million for the first list and $5 million for the second list. The implications of this difference and the benefits and costs associated with collecting the additional (x_3) variable must be evaluated.

Table 7.2. Data evaluation rankings

Rank (all)	Rank (x_1 and x_2)
1	3
2	4
3	1
4	2
5	5

Two suggested applications of the hierarchical Bayesian method demonstrated in this research include the development of predicted rankings and the proactive targeting of sites. Predicted rankings could be used to assess a design policy change (e.g., establishing a three-second all-red interval at all intersections or installation of four foot paved shoulders on all two-lane, rural roads). Changes to sites affected by policy changes or by proposed countermeasures could be used in further analyses to rank the sites and subsequently assess their decline in ranking. Targeting sites proactively is facilitated by evaluation of countermeasures and by the difference between expected and actual crashes. Improved sites that experience a significant reduction in crash history indicate potential for similar sites to be similarly treated, without as much regard for actual crash history. Sites with significant differences between expected and actual crashes indicate types of sites that may warrant further review, despite their actual crash frequency or difference.

Policy Implications

Recently, many transportation agencies have shifted their focus to reduction in severity of crashes. Additionally, citizens and politicians often respond to severe crashes in their area. This implies that severity measures should be examined for inclusion in SICL list development. Incorporation of severity could be accomplished in several different ways.

First, a severity covariate could be included in the current model. This covariate could have levels based on crash or injury severity or value lost (i.e., an economic value placed on severity) for the intersection as a whole. Interpretation of the current dependent variable would require adjustment because crash frequency does not seem to depend on any measure of severity.

Second, the dependent variable could become a measure of severity. Model covariates that predict increased crash severity would then need to be included in the model and those that do not would be removed. For example, speed limit has been previously shown to impact severity and would be retained. Land use does not have an obvious impact on severity and could be dropped.

Third, severity could be included in the economic appraisal and priority ranking phase rather than the network screening phase. Network screening would be used to identify sites of significantly higher crash history than expected. These sites would be reviewed for potential countermeasures and separate economic appraisals developed. Sites with high severities would be more likely to have high economic benefit rankings. However, ignoring severity until this stage might target mitigation efforts more towards frequency rather than severity.

While of interest, dependence on severity alone might not be advisable. The random, rare nature of crashes is more pronounced as crashes become more severe. Analysis based on severity might be more difficult and uncertain. Severity-directed funding might result in improvements to sites with few but more severe crashes. Sites with many but less severe crashes might be ignored. Crash severity is often influenced by factors such as seatbelt use or red-light-running that are mostly outside the control of highway agencies. Both frequency and severity should be incorporated into SICL list development.

Crash frequency is an important factor in identifying sites for further study. However, frequency should not be incorporated directly. Instead, the concept of sites with promise (SWiPs) should be used to incorporate frequency into SICL list development. SWiPs identify sites that are over-represented in terms of crash history, rather than relying on high numbers of crashes. Responding to high rash frequencies would typically lead to mitigation at sites with high volumes, because high volume sites often experience greater numbers of crashes. These sites might not have any definable safety deficiency, other than high volumes. SWiPs indicate those sites that, regardless of volume, are experiencing more crashes than expected. These sites are more likely to have some safety deficiency that can be addressed.

In this research, intersections were considered in their entirety (i.e., on an intersection-wide basis). Recent research has shown that approach-based analyses of intersections have value. Considering intersections on an intersection-wide basis limits results to identification of intersections with over-representation of crashes. This will obscure safety deficiencies occurring on only one approach at the intersections (e.g., over-representation of left-turn crashes). While many of these deficient approaches may be captured in the highly ranked intersections and identified during countermeasure development, some may not be. These latter approaches may be part of intersections that, as a whole, are operating safely. These intersections might have some factor (e.g., traffic patterns) that cause one approach to have high numbers of crashes.

Though many over-represented approaches may be captured in highly ranked intersections, it might be better to identify deficient approaches as part of the initial screening process. Reliance on further engineering analysis might fail to identify these approaches. An analyst might not identify a certain frequency of crashes as over-representative. Consideration of approaches during network screening would provide this information.

The variables included in a model have an obvious impact on results, some more than others. The decisions made during model development impact results. For example, this research focused on intersection crashes and characteristics. Many intersection characteristics that were more difficult to collect were omitted and data aggregation limited some analyses. The model development decisions warrant review for a couple reasons.

First, many variables affecting intersection safety may have been disregarded. This may have resulted in low rankings for sites with safety deficiencies related to these variables. All variables that have potential impact on safety should be reviewed prior to statewide application of the model.

Second, when a model that considers all site categories (e.g., intersections, segments) is developed, inclusion of all safety-related variables is advisable. Again, sites with deficiencies due to certain site characteristics may not be captured if these characteristics are not included. Rankings based on insufficient data would be less valid.

Both approach-based analyses and inclusion of all possible safety-related variables should be discussed in terms of costs incurred versus benefits gained. Though approach-based data can be collected, the benefit gained might be outweighed by the cost of collecting, storing, and maintaining data for all approaches. The same applies to all safety-related variables.

Safety analysts would prefer to have as much information included into the initial ranking as possible. Further review of sites is time-consuming and an analyst might have much information about frequencies of certain crash types but little indication of whether this indicates safety deficiencies. However, data collection, storage, and maintenance can be a costly endeavor and variables that have less impact might result in significant savings if not collected. Review of variables thought to impact safety should clarify the importance of the variables and lead to a compromise benefiting both analysts and data collectors.

APPENDIX A. STATE-OF-THE-PRACTICE SICL

Methods for determining Candidate Locations, High Hazard Locations, or Sites With Promise enable practitioners to determine those sites that they focus their limited safety funds on improving (Traffic Institute 1999). Identification of these locations is a vital component of hazard reduction and safety improvement (Traffic Institute 1999). Focusing on the locations identified, practitioners can address safety concerns and ultimately reduce crash frequency and/or severity (Traffic Institute 1999).

The federally-mandated Highway Safety Improvement Program (HSIP) required each state to "develop and implement, on a continuing basis, a highway safety improvement program which has the overall objective of reducing the number and severity of crashes and decreasing the potential for crashes on all highways (FHWA 1979)." A comprehensive HSIP consists of three components: planning, implementation, and evaluation (TRB 1986).

The planning component should consist of processes which (TRB 1986):

1. collect and maintain data (including crash, traffic, and roadway data),
2. identify hazardous locations and elements,
3. conduct engineering studies, and
4. establish project priorities (i.e., utilize some type of benefit/cost analysis).

Implementation usually involves taking the results of the last two planning components and defining projects, through design and specification. If these projects meet appropriate funding requirements (including benefit/cost requirements) they will then be constructed or implemented.

Evaluation is performed post-construction or implementation to determine the effectiveness of the projects and to improve future HSIP efforts. Evaluation can many times involve some of the same processes as the planning component, namely data collection, identification, and engineering studies.

The crash or hazard mitigation process, as defined by the HSIP, has sometimes been divided into six steps (TRB 2000):

1. identify sites with potential safety problems
2. characterize crash experience
3. characterize field conditions
4. identify contributing factors and appropriate countermeasures
5. assess countermeasures and select most appropriate
6. implement countermeasures and evaluate effectiveness

Step 1 is the same as process 2 of the implementation component, steps 2 through 5 essentially restate processes 3 and 4 from the planning component, and step 6 restates the implementation and evaluation components. Thus, evidence exists supporting the importance of the identification phase to overall safety improvement efforts, whether they are reactive or proactive. In fact, the identification process is the basis, in both listings, for the further processes, in that identification of sites provides analysts and evaluators with a starting point for further study. Without this, they could potentially be faced with the prospect of analyzing and evaluating innumerable sites.

Given this, the identification process needs to be as accurate and informative as possible, resulting in a defensible listing of the sites that are "most hazardous" or that have the "most promise" of crash frequency and severity reduction. However, creating an accurate and informative identification process is not simple and efforts are ongoing to improve and enhance the identification process with both reactive and proactive purposes in mind. This fits well with the HSIP requirement of continuing development and implementation of a highway safety program.

Current and past methods of determining hazardous locations include the following:

State-of-the-Practice (those used by public agencies):

1. Spot Map Method
2. Crash Frequency/Crash Density Methods
    a. Crash Frequency Method
    b. Crash Density Method
3. Crash Rate Method
4. Frequency-Rate Method
5. Quality Control Methods
    a. Number Quality Control Method
    b. Rate Quality Control Method
6. Crash Severity Methods
    a. Equivalent Property-Damage-Only (EPDO) Method
    b. Relative Severity Index (RSI) Method
    c. Critical Rate in Combination with Number Criteria
    d. Other Methods
7. Index Methods
    a. Weighted Rank Method
    b. Crash Probability Index (CPI) Method
    c. Iowa Method
8. Utilize Complementary Methods for Identifying Hazardous Locations

State-of-the-Practice SICL methods are mainly utilized by public agencies on the state and local levels. Many of them have existed for the past couple decades and have not been updated to reflect recent advances in computing and statistics. However, they perform the base function of an SICL method quite well; they result in a ranking list for consideration by analysts and evaluators.

Spot Map Method (SEMCOG 1997) - The spot map method involves the creation of a map showing clusters of symbols at spots and on segments of road network. The map is then examined for geographic clustering of crashes and those having the greatest numbers of total crashes (or total crashes of a particular type) are identified as being high crash locations. The spot map method is extremely simple and easy to use, however it only provides a very rough estimate of high crash locations and does not provide a list of such locations. The spot map method is suitable for small areas and low numbers of crashes but fails for large areas or numbers of crashes. In the latter case, another high-crash identification method would be more advisable.

Crash Frequency Method (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - Closely related to the spot map method, the crash frequency method summarizes the number of crashes for spot locations. Locations are ranked by descending crash frequency and those with more than a predetermined number of crashes are classified as high-crash locations to be further scrutinized for statistical significance.

Application of the crash frequency method involves completion of the following steps for each study location:

1. Determine the crash frequency by computing the annual average number of crashes, preferably for at least the three most recent, consecutive, 12-month periods. Less than three years of data may be used; however, considerable caution must be involved in use of shorter time periods, even for high-volume, high-crash locations.
2. Categorize the location by as many features as reasonable using categories such as:
    a. area type: urban or rural
    b. roadway functional class: arterial, collector, or local (using the higher or highest functional class of the intersecting roadways, where an arterial is the highest class (meant primarily to carry through traffic) and a local is the lowest class (meant primarily to provide access to abutting properties))
    c. number of lanes (the number of through lanes on the widest approach)
    d. predominant traffic control (the presence or absence of signalization)
    e. average daily traffic (ADT) volume (the sum of volumes on all approaches)
3. If previously evaluated locations are being catalogued, insert the new location in its proper order by crash frequency. At a minimum, separate lists for intersections and other spot locations should be maintained. As the list grows, begin to keep lists divided out by more specific combinations of the variables above (e.g., when five or more evaluated locations fall into such a category).
4. Determine the critical crash frequency by using one or both of the following approaches for each location type:
    a. Utilize a list of critical crash frequencies, if one has been developed for your state or region. If none exist, these critical crash frequencies can be computed with crash data for the entire state or region using the following equation:

    $$F_{cr} = F_{av} + s_F$$

    where:

    F_{cr} = critical crash frequency,
    F_{av} = average crash frequency for all locations of a given type, and
    s_F = standard deviation of crash frequency for all locations of this type.

    Local critical crash frequencies may also be calculated using this equation and the appropriate statistical methods. That is, if a local critical crash frequency is computed, be sure to verify that the sample size is sufficient.

    b. Choose a number of crashes per year (or per year per mile) which is considered "high" and unlikely to be exceeded by many similar locations. This enables an agency to determine a reasonable number of sites for detailed study. This number is subjective and highly empirical.

5. Compare the location's crash frequency to the critical crash frequency. If the critical crash frequency is equaled or exceeded, classify the location as a high-crash location.

The crash frequency is typically used as a basic measure of the safety at a spot location while crash density is used for roadway sections.

Crash Density Method (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - Closely related to the crash frequency method, the crash density method summarizes the number of crashes per mile for highway sections. Sections are defined as a minimum length of roadway with consistent characteristics, with the minimum distance used frequently being one mile. Locations are ranked by descending crash density and those with more than a predetermined density of crashes are classified as high-crash locations to be further scrutinized for statistical significance.

Application of the crash density method involves completion of the same steps as for the crash frequency method, but determining crash densities for each study location:

1. Determine the crash density by computing the annual average number of crashes per mile, preferably for at least the three most recent, consecutive, 12-month periods. Less than three years of data may be used; however, considerable caution must be involved in use of shorter time periods, even for high-volume, high-crash locations. The number of crashes is divided by the segment's length in miles to create a comparison measure with which to rate against other segments.
2. Categorize the location by many features as reasonable using categories such as:
   a. area type: urban or rural
   b. roadway functional class: arterial, collector, or local
   c. number of lanes
   d. predominant traffic control (the speed limit)
   e. average daily traffic (ADT) volume
3. If previously evaluated locations are being catalogued, insert the new location in its proper order by crash density. As the list grows, begin to keep lists divided out by more specific combinations of the variables above (e.g., when five or more evaluated locations fall into such a category).
4. Determine the critical crash frequency by using one or both of the following approaches for each location type:
   a. Utilize a list of critical crash densities, if one has been developed for your state or region. If none exist, these critical crash densities can be computed with crash data for the entire state or region using the following equation:

$$D_{cr} = D_{av} + s_D$$

where:

D_{cr} = critical crash density,
D_{av} = average crash density for all locations of a given type, and
s_D = standard deviation of crash density for all locations of this type.

Local critical crash densities may also be calculated using this equation and the appropriate statistical methods. That is, if a local critical crash density is computed, be sure to verify that the sample size is sufficient.

b. Choose a crash density per year (or per year per mile) which is considered "high" and unlikely to be exceeded by many similar locations. This enables an agency to determine a reasonable number of sites for detailed study. This number is subjective and highly empirical.

5. Compare the location's crash density to the critical crash density. If the critical crash density is equaled or exceeded, classify the location as a high-crash location.

The merits of the crash frequency and crash density methods include their simplicity and the fact that locations with many crashes would be studied. However, no consideration for exposure (e.g., traffic volumes) in the prioritization occurs. This lack can result in misleading results if traffic volumes vary considerably throughout the road system. The crash frequency and crash density methods tend to rank high-volume locations as high-crash locations, even if the relative number of crashes is low given its volume.

Many agencies that use the crash frequency and crash density methods only use them to develop an initial list and evaluate the locations in the list in more detail using other methods.

Crash Rate Method (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - The crash rate method factors the risk of exposure into the determination of high crash locations. The method uses crash rate (number of crashes divided by vehicle exposure) as a basis for ranking. Rates are given in crashes per million entering vehicles (crashes/MEV) for spot locations and crashes per million vehicle-miles (crashes/MVM) for sections. Locations with higher than a predetermined rate are classified as high-crash locations.

Crash rates are calculated using:

$$\text{Crash rate} = a/v$$

where:

a = the number of crashes at a location during a specified time
v = the traffic volume using the location during that same time

Due to the rarity of crashes, this rate is generally multiplied by one million or one hundred million.

Two kinds of rates are generally computed, one for spots and one for sections:

1. The spot crash rate involves the number of crashes per million vehicles entering the spot:

$$R_i = 2\,(A)\,(1{,}000{,}000)\,/\,(T)\,(V)$$

where:

R_i = spot crash rate expressed in crashes per million entering vehicles
A = number of crashes during the days of the study
T = time period in days
V = total average daily traffic entering and departing the intersection

2. The section rate considers section length in addition to volume. Because road sections vary in length, they provide different exposure to crashes; thus, rates for road sections must be in terms of crashes per one million miles or one hundred million miles. Road sections are generally longer than half a mile and usually 100 million vehicle miles are used. The section rate is calculated using:

$$R_s = (A)\ (100{,}000{,}000)\ /\ (T)\ (V)\ (L)$$

where:

R_s = section rate in crashes per 100 million vehicle miles
V = average annual daily traffic on a section (vehicles per day)
T = period (days) for which crashes are counted, usually 365 days
L = length of section in miles

A stepwise method of determining crash rates and developing a list is as follows:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Calculate crash frequencies at individual spots and crash densities along each established section.
3. Using the section crash rate equation, calculate the crash rate for each established section during the study period.
4. Using the spot crash rate equation, calculate the actual crash rate for each intersection or spot during the study period.
5. For the same period, calculate the system-wide average crash rates for sections and spots. Use the appropriate equation (for sections or for spots), inserting the summation of total crashes, total vehicle miles, and total vehicles, respectively, for each category of location.
6. Select crash rate critical values as criteria for identifying high crash locations. Doubling the system-wide rate is usually reasonable and pragmatic.

Selection of the critical values is not completely necessary. The principal purpose is to limit the high crash location list length in order to expedite investigation. Experience will disclose the proper level for a particular agency. Additionally, an agency might simply consider only a certain number of locations (e.g., the top 200).

7. If actual rates exceed the minimum established criteria, the location is identified as a high crash location and placed on the list for investigation and analysis.

The principle reason for using the crash rate method is that it considers exposure in the form of traffic volume. A road location or section might have a high number of crashes simply due to use rather than its being hazardous. Use of crash rate mitigates this. Generally, the crash rate method provides better results than the crash frequency or crash density methods. However, it is more complex than either of those methods, especially as it adds the further complication of requiring non-crash data.

Use of either the crash frequency, crash density, or crash rate methods to identify hazardous locations has its shortcomings. The two-fold purpose of the crash or hazard mitigation process is identification of unsafe locations and simultaneous designation of areas with greatest promise for crash and/or crash severity reduction. Whereas the crash frequency and crash density methods designate the second purpose and the crash rate method designates the first purpose, neither fully addresses the complementary purpose. Improvement can be achieved through use of the frequency-rate method or the quality control methods. These latter methods are recommended for agencies with large, complex systems.

Frequency-Rate Method (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - The frequency-rate method is a combination of crash frequency/crash density methods and the crash rate method. Locations are classified as high-crash locations if they have more than the prescribed minimum crash frequency or crash density and higher than the minimum crash rate.

The crash frequency/crash density methods and the crash rate methods have deficiencies that limit their effectiveness. However, if these methods are combined, as they are in the frequency-rate method, it appears possible to eliminate or minimize the effects of the deficiencies.

The steps involved in the frequency-rate method are as follows:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Identify crash frequencies for individual spots and crash densities along each established section.
3. For sections, compute average crash density and crash rates for each category of highway, based on total data for all sections of each category:

   Average crash density = E(crash frequency)/E(miles)

   Average crash rate = E(crash frequency)(10^6)/E(section ADT)(no. of days)(section length)

4. For spots, compute average crash frequencies and rates for each category of highway, based on total data for all spots of each category:

   Average crash frequency = Total crash frequency/Total number of locations

   Average crash rate = (Total crash frequency)(10^6)/E(location ADT)(no. of days)

5. Select critical values for each of the criteria above. Begin by doubling the system-wide average for each highway category.
6. For each section, calculate both the crash density and crash rate.
7. For each spot, calculate both the crash frequency and the crash rate.
8. All locations with crash frequency/crash densities and crash rates both higher than the critical values should be placed on the high crash location lists, one for each category of locations. Comparisons must be made with criteria for the particular category of highway being analyzed.

The crash frequency or crash density is used to create the initial list and the crash rate is used to reorder the final list. The number of sites studied further should be commensurate with the staff assigned to conduct additional studies.

The frequency-rate method combines two methods that have different deficiencies, thus minimizing or eliminating these deficiencies. Sites with high crash frequencies/densities might appear to be problematic but if the traffic volumes are also high, the crash rates might then not be high enough to meet the critical value. On the other hand, sites with high crash rates due to extremely low traffic volumes might have low crash frequencies/densities, thus not meeting the critical values. To be classified as a high crash location, sites must meet both criteria and thus be deemed worthy of additional investigation.

However, in conclusion it must be clarified that the deficiencies might only be minimized. Sites that should be investigated further might not be, resulting in a loss of potential crash reduction. Sites that shouldn't be investigated further might be, utilizing time better spent investigating truly hazardous sites.

Though all of the above methods generate useable lists for hazardous site ranking, none of them include any measure of statistical significance or any statistical control. However, a couple currently utilized methods exist that incorporate some simple statistics, one based on crash frequency/density and one based on crash rate:

Quality Control Methods (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 2000) - Similar to the frequency-rate method, the quality control methods consider various highway categories. These methods assure quality control of the analysis by applying a statistical test for determination of unusual crash frequencies/densities or rates. The analysis involves testing the site crash frequencies/densities or rates against predetermined average values for sites with similar characteristics. The statistical tests are based on the oft-accepted premise that crashes fit the Poisson distribution. The critical values are determined using a function of system-wide average crash frequencies/densities or rates for various highway categories and vehicle exposures at the location being studied (the latter of these for rates only). This function incorporates some statistical control by inserting a Poisson distribution probability constant.

Number Quality Control Method (Traffic Institute 1999; TRB 2000) - The number quality control method identifies those sites where crash frequency or crash density is greater or significantly greater than the average crash frequency or density for similar sites across the state or similar region. Similar to the crash frequency and crash density methods, the number quality control method adds some form of statistical control for selecting the critical crash frequency/crash density.

The number quality control method applies a statistical test to determine the significance of a site's crash frequency/density when compared to the mean crash frequency/density for similar sites. The statistical test applied is based on the Poisson distribution, the commonly accepted distribution for crashes. Use of the number quality control method effectively addresses sites with high crash frequencies/densities but low exposures. Inputs for the number quality control method, for identification of hazardous sites, include: average crash frequency/density for site category, crash frequency/density at the site, and level of statistical significance.

Determination of each site category's average crash frequencies/densities must be done with care, considering the nature of the sites and their surrounding environment. Site categorizations must be carefully designated and each site then assigned to a particular category. Site categories can be developed using a variety of features, including: rurality, number of lanes, surrounding land use, road types, etc. The purpose of the categories is to facilitate comparison of site crash frequencies/densities with like sites, to the degree possible.

However, this categorization of sites can be taken to unreasonable limits. Therefore, limiting the number of categories to a number which is tenable (that is, neither too large to be unmanageable or that would reduce sample size below statistical reliability nor too small to adequately describe sites) is strongly advised. One suggested breakdown utilizes a combination of rurality of the roadway (urban or rural) and the number of lanes. The categorization utilized should reflect the question being addressed.

After categories have been established, computation of the average frequencies/densities for each category ensues. Many state transportation agencies calculate statewide averages for many categorizations. To compute the critical crash rate for a site, use the following equation:

$$F_c = F_a + k\,(F_a/M)^{1/2} + 1\,/\,2M$$

where:

F_c = the critical crash frequency/density
F_a = average crash frequency/density for the entire population of sites within the category
k = a probability constant, where the higher the value of k, the higher the value of the critical crash frequency/density. Some common k values are:

- k = 3.090 for a 99.9% level of confidence
- k = 2.576 for a 99.5% level of confidence
- k = 1.645 for a 95% level of confidence
- k = 1.282 for a 90% level of confidence

M = millions of vehicle miles (or kilometers) for sections or millions of vehicles for spots

Use of a high k value will result in a shorter list of critical sites but confidence that those sites are hazardous is increased. Critical crash frequencies/densities for low ADT highways are higher because fewer crashes occur within low exposure sites. Also, the use of multiple years of crash data lowers critical crash frequencies/densities due to the variability of crashes at a site over time.

Using the above equation, develop for each categorization a list of critical sites and order them by a Safety Index, which is simply the actual frequency/density divided by the critical frequency/density. The steps involved in using the number quality control method are:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Compute system-wide average frequencies/densities for each category of highway, based on total data for all sites in each category.
3. For each site, determine the vehicle exposure, M, during the study period.
4. Compute the critical crash rate, F_c, for each site within each category using the equation above.
5. Compute the actual observed crash frequency/density at each site for the same time period.
6. Compare the actual crash frequency/density with the critical frequency/density for each site and prepare a list of all sites within each category with frequencies/densities exceeding the critical value.
7. Compute the Safety Index for each site and rank the list for each category by the Safety Index.

Rate Quality Control Method (HRGreen 2001; SEMCOG 1997; Traffic Institute 1999; TRB 2000) - The rate quality control method identifies those sites where crash rate is greater or significantly greater than the average crash rate for similar sites across the state or similar region. Similar to the crash rate method, the rate quality control method adds some statistical control for determining the critical crash rate.

The rate quality control method applies a statistical test to determine the significance of a site's crash rate when compared to the mean crash rate for similar sites. The statistical test applied is based on the Poisson distribution, the commonly accepted distribution for crashes. Use of the rate quality control method effectively eliminates sites with high crash rates but low exposures. Inputs for the rate quality control method, for identification of hazardous sites, include: average crash rate (per 100 million vehicle miles) for site category, crash rate at the site, and level of statistical significance.

Determination of each site category's average crash rates must be done with care, considering the nature of the sites and their surrounding environment. Site categorizations must be carefully designated and each site then assigned to a particular category. Site categories can be developed using a variety of features, including: rurality, number of lanes, surrounding land use, road types, etc. The purpose of the categories is to facilitate comparison of site crash rates with like sites, to the degree possible.

However, this categorization of sites can be taken to unreasonable limits. Therefore, limiting the number of categories to a number which is tenable (that is, neither too large to be unmanageable or that would reduce sample size below statistical reliability nor too small to adequately describe sites) is strongly advised. One suggested breakdown utilizes a combination of rurality of the roadway (urban or rural) and the number of lanes. The categorization utilized should reflect the question being addressed.

After categories have been established, computation of the average rates for each category ensues. Many state transportation agencies calculate statewide averages for many categorizations. To compute the critical crash rate for a site, use the following equation:

$$R_c = R_a + k\,(R_a/M)^{1/2} + 1 / 2M$$

where:

R_c = the critical crash rate
with:
Crashes per Million Vehicle Miles (MVM) or Million Vehicle Kilometers (MVK)m used for Sections
Crashes per Million Vehicles (MV) used for spots
R_a = average crash rate for the entire population of sites within the category
k = a probability constant, where the higher the value of k, the higher the value of the critical crash rate. Some common k values are:
k = 3.090 for a 99.9% level of confidence
k = 2.576 for a 99.5% level of confidence
k = 1.645 for a 95% level of confidence
k = 1.282 for a 90% level of confidence
M = millions of vehicle miles (or kilometers) for sections or millions of vehicles for spots

Use of a high k value will result in a shorter list of critical sites but confidence that those sites are hazardous is increased. Critical crash rates for low ADT highways are higher because fewer crashes occur within low exposure sites. Also, the use of multiple years of crash data lowers critical crash rates due to the variability of crashes at a site over time.

Using the above equation, develop for each categorization a list of critical sites and order them by a Safety Index, which is simply the actual rate divided by the critical rate. The steps involved in using the rate quality control method are:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Compute systemwide average number of crashes per MV or MVM for each category of highway, based on total data for all sites of each category.
3. For each site, determine the vehicle exposure, M, during the study period.
4. Compute the critical crash rate, R_c, for each site within each category using the equation above.
5. Compute the actual observed crash rate at each site for the same time period.
6. Compare the actual crash rate with the critical rate for each site and prepare a list of all sites within each category with rates exceeding the critical value.
7. Compute the Safety Index for each site and rank the list for each category by the Safety Index.

As mentioned, the quality control methods utilize a statistical test to refine the decision-making process involved in determining a site's hazardousness. Also, these methods allow agencies to determine priorities by grouping locations according to their functional classification and rank within these classifications. Also, sites having higher crash frequencies than average for their category can be quickly singled out for special attention. Though this improves over the previous methods, it still has noteable deficiencies.

First, the statistical test utilized is somewhat ambiguous and suspect. The addition of the Poisson distribution probability constant adjusts the critical rate equation in order to limit the number of sites judged critical. However, the reasoning behind the use of this probability constant in the equation is somewhat unclear. Adjusting the critical rate by a standard deviation or two fits with standard statistical practice, but the third element in the equation (1 / 2M) has a less clear meaning. Additionally, the entire premise of crashes being distributed as per the Poisson distribution has been questioned in recent literature. The Negative Binomial distribution has, recently, been judged a better representation. This may not matter due to the simplicity of this equation and its intended use, but it might introduce some bias due to overdispersion. Finally, the choice of which k-factor value to pick is highly subjective, giving rise to possible ambiguity in results from year to year.

Second, the method is quite data intensive, if simply because it needs to be in order to achieve the gains. For each site and site category the user must track several different types of data that wouldn't be needed under the spot map, crash frequency/density, crash rate, and frequency-rate methods. The categorization development process involves the subjective determination of categories through examination of site characteristics throughout the jurisdictional region. Many site characteristics are now in computerized databases but not all, thus requiring some data collection. Then, once the site categorizations have been developed, each site must be categorized and the method steps listed above must be run for each site within each category.

Third, only crashes and volumes are included in the equation. While the categorizations address other types of data, as the categorizations become more refined, more data must be collected. Again, this might be the price of better refinement in list generation.

Thus far, none of the methods have addressed the idea of including crash or injury severity into the determination of hazardous site ranking lists. However, there are a series of methods which account for severity for list generation:

Crash Severity Methods (SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - Several methods exist that incorporate severity, either of the crashes or of the injuries, into the SICL process. These methods utilize a variety of methods to incorporate severity measures, including: frequency/density of more severe crashes, rate of more severe crashes, and ratio of more severe crashes. Essentially, those crashes or injuries judged more severe are given more relative weight than those judged less severe. Sometimes the results for each site are then compared, as in the quality control methods, to systemwide averages for similar roadways. This inclusion of severity enables highway agencies to devote more of their safety resources to locations with greater exhibited potential for injury or loss of life, thereby allowing the treatment of these locations for reducing overall system severity.

To define severity of crashes and injuries, a standard definition of severity levels has been defined by the National Safety Council (NSC) and is an American National Standards Institute (ANSI) standard (Ogden 1996):

Fatal: one or more deaths (commonly signified by K)
A-level injury: incapacitating injury preventing victim from functioning normally (e.g., paralysis, broken/distorted limbs, etc.)
B-level injury: non-incapacitating but visible injury (e.g., abrasions, bruising, swelling, limping, etc.)
C-level injury: probable but not visible injury (e.g., sore/stiff neck)
PDO: property-damage only (commonly signified by 0)

Known as the KABC0 injury scale, it is used commonly in police reporting of crashes. Many of the crash severity methods utilize this scale.

Equivalent Property-Damage-Only (EPDO) Method (SEMCOG 1997; Traffic Institute 1999; TRB 1986,2000) - In the equivalent property-damage-only (EPDO) method weights fatal and injury crashes against a baseline of property-damage-only crashes. Each of the injury levels (KABC) are given a specific number weight that is compared against property-damage-only crashes, which are given a weight of 1. These weight coefficients are based on the relative average crash costs by severity. K-type and A-type crashes often have the same weight. The weights are incorporated into the SICL process by either computing a EPDO index or an EPDO rate.

The steps involved in utilizing the EPDO method for a site are:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Split the crashes by severity level, assigning each crash to a severity level based on its worst severity injury.
3. Calculate the EPDO Severity Index (SI) using the following equation:

$$SI = [W_K K + W_A A + W_B B + W_C C + P] / T$$

   where:

   SI = Severity Index for the site
   W = the respective weight coefficients
   K = frequency of fatal crashes at the site
   A = crash frequency involving A-type injuries at the site
   B = crash frequency involving B-type injuries at the site
   C = crash frequency involving C-type injuries at the site
   P = frequency of PDO crashes at the site
   T = total crashes at the site

4. Calculate the EPDO index using the following equation:

$$\text{EPDO Index} = W_K K + W_A A + W_B B + W_C C + P$$

   where the variables are the same as above.

5. Calculate the EPDO rate using the following equation:

$$\text{EPDO Rate} = [\text{EPDO Index x } 10^6 \text{ or } 10^8] / [(\text{Exposure per day}) \text{ x Days}]$$

6. Categorize the site as per the quality control methods.
7. Compare the site SI, EPDO Index, and/or EPDO Rate to its respective category critical values to determine the hazardousness of the site. If the site's values exceed the category critical values, include the site on the hazardous site list. Rank the list by either EPDO Index or EPDO Rate.

For step 2 it is important to note that the more severe crash types are less likely to occur. Therefore, several years of data may be required to compute a meaningful EPDO Index or Rate. However, great care should be exercised when using multiple years to insure that traffic and road characteristics have not changed significantly during the analysis period.

The EPDO Method improves on the previous methods in that it includes crash severity. However, the method, like the quality control methods, require more data than the simple crash frequency/density or crash rate methods. Gains in hazardous site identification might be sufficient to warrant this, however.

Relative Severity Index (RSI) Method (SEMCOG 1997; TRB 1986,2000) - The relative severity index (RSI) method incorporates the weighted average cost of crashes at sites. This method is best-suited for the further evaluation of sites already identified by other methods as high-crash sites. In the RSI method, crash frequency at each severity level is multiplied by the average "comprehensive cost" for crashes at that severity level. The subtotals for each of these severity-specific costs are summed and the sum is divided by the total crash frequency.

The RSI method, step-by-step, is:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Split the crashes by severity level, assigning each crash to a severity level based on its worst severity injury.
3. Compute the RSI value for the site, utilizing the severities in the following equation:

$$RSI = [C_F K + C_A A + C_B B + C_C C + C_P P]/(K+A+B+C+P)$$

where:

C_i = the average comprehensive cost per crash for a crash of severity level "i" from K thru P
K, A, B, C, and P are as defined above in the EPDO method.

11. Assign the site into a site category, much like the quality control methods, and compare the site's C_i against the category's critical C_i. If the site has critical C_i, insert it into the list of sites for that category, ranked by C_i.

The RSI method allows for crash severity to be included in SICL list generation. However, it also requires, much like the quality control and EPDO methods, more information about each site than the simpler methods. Additionally, the RSI method, through its use of severity cost values, introduces proxy measures into the computation, rather than utilizing the data as is. If these proxy measures are not accurate, the calculations and lists generated using them will be inaccurate.

Critical Rate in Combination with Number Criteria (Traffic Institute 1999) - The critical rate in combination with number criteria method is based on warrants. The warrants include a concentration criteria and a severity criteria. To meet the concentration criteria, a site has to have exceeded a certain frequency/density of crashes for a period of years and another frequency/density of crashes for one year. To meet the severity criteria, a site must have an EPDO rate exceeding a certain level (e.g., 2 crashes/MEV). Critical rates for total crashes, night crashes, fatal crashes, etc. can also be utilized to determine high-hazard sites.

Other Methods (Traffic Institute 1999) - Some agencies use the ratio of fatal crashes to total crashes. Others calculate fatal crash rates, fatal plus injury crash rates, and total crash rates for each facility type. They then use these average rates to determine a site's hazardousness.

Crash severity methods are an excellent way to incorporate into the SICL process the information that is collected about the cost of crashes to individuals and society. However, not only are they somewhat subjective and thus somewhat subject to error, they also require more data for accurate results. Where crash frequency is small, more severe crashes can quickly control the results even though these more severe crashes might be caused by factors unrelated to the highway condition. If not given proper consideration, the crash severity method results could lead to erroneous expenditures of safety improvement funds for sites where crash severity may not be sensitive to highway treatments. Currently, proper consideration is provided by analysts surveying the crash reports for each of those sites identified as being hazardous. Efforts are underway, however, to automate this process, some effort through database management, some effort through improved, more informative statistical procedures. Another way to mitigate this potentiality is to utilize more information about non-severity indicators in the methodologies.

Index Methods (SEMCOG 1997; Traffic Institute 1999; TRB 2000) - Three index methods exist which attempt to incorporate severity indices with other previously described methods. These two index methods are the weighted rank method, the crash probability index (CPI) method, and the Iowa Method.

Weighted Rank Method (Traffic Institute 1999; TRB 2000) - The weighted rank method combines some of the previous methods in the calculation of a single index value for each site. Many times the weighted rank is created by giving equal weight to as many as five indicators, such as: crash frequency/density, crash rate, percentage of wet crashes, percentage of night crashes, and crash severity (utilizing a simple 5-point scale). A ranked list is prepared for each of the five indicators and then the ranks for each site within these lists are combined based on the weighting schema to produce a combined list. The list thus created is then ranked based on the weighted value.

The premise of the weighted rank method is to retain some benefits from each of the different measures while simultaneously eliminating or minimizing the disadvantages. The method also allows agencies to change weightings based on their priorities. Obviously, using the weighted rank method requires more effort, as an agency is required to produce several lists in order to develop the final weighted list. Also, the weightings determined by the agency, if not carefully researched, can be highly subjective.

Crash Probability Index (CPI) Method (SEMCOG 1997) - The crash probability index (CPI) method, much like the weighted rank method, combines the results from previous methods: frequency/density, rate, and severity. The combination, in theory, reduces the misleading results for high-volume and low-volume sites while also inserting severity. Again, like the weighted rank method, the CPI method allows analysts to adjust weightings to reflect agency priorities.

As part of the CPI method, when a site has significantly worse than average crash frequency/density, crash rate, or severity distribution, it is assigned penalty points. The overall CPI for a site is a summation of the penalty points across these three measures. A final ranking list for all sites, ranked by descending CPI, is generated.

Application of the CPI method includes:

1. If not already done, locate all crashes in accordance with accepted coding practices.
2. Determine the each site's crash frequency/density, crash rate, and casualty ratio (CR). Utilize the following equation to compute CR:

   $$CR = (F+A+B+C)/(F+A+B+C+P)$$

   where the variables on the right side of the equation are as defined previously in the EPDO method.

3. Categorize the site as per the quality control methods.
4. Determine the critical values for crash frequency/density, crash rate, and casualty ratio. The former two of these are as described in the quality control methods. The critical casualty ratio is determined for the site's category as well.
5. Compute the CPI value for the site by comparing the site's values computed in Step 2 to their critical values as follows:
   a. If neither the crash frequency/density, crash rate, nor the casualty ratio equals or exceeds their corresponding critical values, the CPI for the site is zero.

b. If the crash frequency/density equals or exceeds the corresponding critical crash frequency/density, assess five penalty points.

c. If the crash rate equals or exceeds the corresponding critical crash rate, assess five penalty points.

d. If the casualty ratio equals or exceeds the corresponding critical casualty ratio, assess ten penalty points.

e. Sum the sub-CPI penalty points to obtain the site CPI.

To adjust for agency priorities, adjust each of the sub-CPI penalty points appropriately and apply over all sites considered in the same analysis.

6. Remove any zero CPI sites from analysis.
7. Retain sites with non-zero CPIs and classify them as either: first-class (20 points), second-class (10-15 points), or third-class (5 points). First class sites are of highest priority, while third-class sites receive less immediate attention.

The classification point levels should be adjusted if the sub-CPI penalty points have been adjusted.

Again, like the weighted rank method, the CPI method attempts to utilize the best features of the incorporated methods while eliminating or minimizing the bad features. Agency priorities are also accommodated. The CPI method also, however, requires more effort as it incorporates more methods. Additionally, adjustment of the sub-CPI penalty points can be highly subjective.

Iowa Method (Estochen 1999; TAS 1997) - In Iowa, in an approach similar to that of the Weighted Rank Method, three ranking lists are generated and then the ranks from these three lists are combined into a single rank. The three sub-lists are a frequency rank, a rate rank, and a severity rank, this last based on "value loss" at the site.

The three sub-rankings have historically been generated using a link-node system for crash location. The link-node system involved the placement of nodes at locations including intersections, grade separations, bridges, ramp termini, severe curvature, and railroad crossings. These locations all have a unique identifier for its geographic location. Each crash at these locations is referenced to this unique location, or reference node. Crashes between these locations are referenced to both the nearest node (the reference node) and the node at the other end of the roadway link (the direction node), with a distance from the reference node specified as well. The total number of crashes that occur at each reference node and reference node/direction node pair can then be easily tabulated. However, only a list for reference node crashes is generated. To enter the first list the number of crashes must meet one of three certain criteria: a fatality, X number of injury crashes, or Y number of property damage crashes. Currently, X is set at 5 and Y is set at 8. This list typically results in 10,000 to 11,000 locations annually. However, the link-node system has been abolished and a switch to a coordinate-based system is in effect. Adjusting the Iowa SICL method to reflect this is one of the challenges for the Office of Traffic and Safety.

The first two rankings lists are generated much the same as, respectively, the crash frequency/density methods and the crash rate method. Because Iowa has historically relied on a link-node system, the definition of a site, whether spot or section, is slightly affected. In fact, three different types of sites were generally defined:

1. **Intersections** include all road-to-road intersections, except alleys, ramp terminals, and complex intersection or interchange sites.

2. **Links** include sections of road between intersections or nodes.
3. **Nodes** include rail to road intersections, grade separations, bridges, road ends, 90 degree turns, county lines, and major signalized commercial entrances.

Steps involved in the Iowa Safety Improvement Candidate Location (SICL) development process are:

1. The crash statistics are searched to identify all locations (intersections, links, and nodes) in the State that meet at least one of the following crash frequency requirements for the designated five-year time period to develop the candidate location file:
   a. at least one fatal crash, or
   b. at least four personal injury crashes, or
   c. at least eight total crashes.
2. The candidate location file created in Step 1 is sorted by descending frequency of crashes and a frequency rank is assigned.
3. For each site in the candidate location file, the frequency of each category (as defined by the KABCO scale) of injury is determined. A value loss is determined using these injury severity frequencies using the following values (updated in 2001):
   a. Fatalities x $1,000,000, plus
   b. Major Injuries x $150,000, plus
   c. Minor Injuries x $10,000, plus
   d. Possible/Unknown Injuries x $2,500, plus
   e. Actual Total Property Damage or $2,500 if unknown.

   A value loss rank, generated by sorting the value losses in descending order, is assigned.
4. Crash rates per million entering vehicles are calculated for sites with known traffic exposure data. The sites are sorted by rank in descending order and a crash rate ranking is assigned to each site. Sites with no traffic exposure data are initially assigned a rank of 0 to give these sites the highest possible priority in the rate ranking. Traffic volumes are then determined, from any credible source, for sites with a rate rank of 0 that fall within the top 200. This process continues until all sites within the top 200 have valid rank values for rate.

   Crash rates per million entering vehicles are calculated as:

   Rate=(Frequency)(1,000,000)/(DEV)(5 Years)(365 Days/Year)

   where DEV is the actual DEV for spot locations and road segments up to 0.6 miles long.

   For road segments 0.6 miles long and longer the DEV is calculated as:

   DEV=ABS((Link Length/0.3)(DEV))

   This calculation adjusts the daily entering vehicles by the number of 0.3 mile sections within the segment to correlate the crash rate for longer segments closer to that for a spot location or shorter segment. This is an attempt to enable comparisons between spot locations and segments and enables one rank list, rather than 2 or 3, to exist.

5. The three rankings, frequency, value loss, and rate, are summed to create a composite rank factor. The sites are then sorted in ascending order by this composite rank factor and assigned a composite state ranking.

The Iowa method has many of the same positive features and negative features of those methods it incorporates: frequency, rate, and severity.

Though all these methods develop lists for further consideration, they are not the only ways that sites can be identified as hazardous. Many non-crash based methods exist which might aid in proactively determining hazardous locations prior to existence of a crash history. These methods may also complement the identification of hazardous sites by verifying the existence of problems or by clarifying those problems.

Utilize Complementary Methods for Identifying Hazardous Locations (Traffic Institute 1999) - Complementary methods utilize non-crash indicators to aid in identifying the most hazardous location. They include:

1. Results of road skid testing
2. Hazard Indicator reporting
3. Observed minor crashes
4. Observed near-crashes
5. Evidence of potential hazards such as skidmarks at intersection approaches
6. Maintenance records
7. Median or shoulder encroachment wheel marks
8. Volume to capacity ratios
9. Stopping and passing sight distance
10. Access points (driveways)
11. Traffic conflicts analysis
12. Erratic maneuver observations
13. Reports of hazardous locations by highway personnel, police, department personnel, motor clubs, motorists, and others.

Though all of these "state-of-the-practice" methods have proven useful, none address the identification of high crash locations thoroughly. In addition to the problems with each stated previously, all the methods ignore a significant majority of the system-wide sites in their analyses. Sites without any crashes in the time period analyzed are routinely ignored. This directs all mitigation measures to a reactive, rather than proactive, role. While consideration of only those sites having a crash history makes direct sense from a crash reduction standpoint, consideration of sites without a crash history is more difficult to justify. However, inclusion of sites without a crash history allows for analysis of those factors about the sites that might lend themselves to safety or the lack thereof. Of course, to determine the problems on a systematic basis requires much more effort than obtaining crash histories and traffic volume data. To properly analyze sites to determine their deficiencies, a system-wide database containing the relevant attributes must be polled, thereby increasing the level of effort required to create a ranking list.

APPENDIX B. 15-YEAR IOWA TOP 500 LISTS

The Iowa DOT has for several years maintained a priority ranking candidate list. Typically, only the top 200 sites statewide are retained for possible further analysis. However, during development of the candidate list, approximately 10,000 sites are initially considered. These sites all meet a criteria of at least one fatal crash, four injury crashes, or 8 total crashes. After this initial list of 10,000 is created, frequency, rate, and severity rankings are produced. During the process, not all sites have an easily obtainable volume (i.e., from a database). At this point, an iterative procedure begins which ensures that the final top 200 sites all have valid volumes. Many times, this results in most of the final top 500 sites having a volume. Table B.1. contains a 15-year listing of the Iowa top 500 sites, sorted by the most recent list (shaded row), completed for 1995 through 1999 data.

Table B.1. 15-year Iowa top 500 list

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Des Moines	Int Porter Ave & Sw 9th St	99999	264	194	198	2	1	1	1
Des Moines	Int Guthrie Ave & E 14th St	99999	16	25	19	10	11	2	2
Des Moines	Merle Hay/ Ovid Ave To Douglas	35	34	86	26	11	9	6	3
Cedar Rapids	Int Collins Rd & Northland Av Ne	99999	398	227	99999	59	19	7	4
Sioux City	Int 14th St & Douglas St	99999	99999	99999	402	9	8	5	5
Des Moines	Int Park Ave & Se 14th St	99999	27	2	12	8	10	4	6
Davenport	Int Us 6 & Welcome Way	99999	94	107	76	103	54	9	7
Altoona	Nb Us 65 Rp @ Us 6	99999	99999	99999	99999	99999	329	18	8
Council Bluffs	Int 24th St & 27th Ave	99999	99999	99999	99999	99999	29	15	9
Des Moines	Int Beaver Ave & Douglas Ave	99999	43	34	18	5	4	3	10
Davenport	Int Us 61 & W 65th St	99999	23	45	33	168	15	20	11
Muscatine	Jct Us 61/ia 22/ia 38	99999	110	90	101	33	12	23	12
Sioux City	I-29/us 77 Platform/ Se Cor	99999	262	345	292	180	133	25	13
Des Moines	Int University Ave & E 9th St	99999	122	92	288	121	172	11	14
Ames	Int S Duff Ave & S 16th St	99999	99999	99999	99999	99999	99999	30	15
Rural	Us 69 At Wb I-35/80 Ramps	99999	99999	99999	99999	124	69	21	16
Des Moines	Jct Us 65/ia 163 & E 30th St	99999	205	162	81	52	24	22	17
Des Moines	Int Holcomb Ave & 2nd Ave	99999	52	47	39	87	214	14	18
Algona	Us 169/ E Fork Dm Riv To Us 18	99999	191	164	194	139	97	98	19
Des Moines	Int Ingersoll & 42nd St	99999	251	215	226	114	201	34	20
Carroll	Int Us 30 & Grant Rd	99999	400	501	99999	99999	218	32	21
Ames	Int Grand Ave & Lincoln Way	99999	99999	99999	449	99999	367	169	22
Ottumwa	W Jct Us 34 & Us 63	99999	174	181	192	115	37	37	23
Des Moines	Int 19th St & University Ave	99999	42	95	95	16	17	17	24
Fort Madison	Us 61/ia 2/ Ortho Rd To 44th St	16	15	33	8	20	136	57	25
Indianola	Int Us 65/69 & Valley Pl Dr	99999	99999	99999	99999	99999	99999	182	26
Des Moines	Int E Army Post Rd & Se 14th St	99999	26	11	80	75	114	42	27
Des Moines	Int Grand Ave & E 15th St	99999	57	74	117	100	206	47	28
Ottumwa	Int Us 34 & Us 63	99999	99999	245	142	80	60	36	29
Des Moines	Int University Ave & E 21st St	99999	103	39	100	108	233	65	30
Des Moines	Int Hubbell(us 6/65) & E 38th St	99999	223	256	380	231	140	33	31
Davenport	Int Fairmount St & Kimberly Rd	99999	99999	410	361	13	16	29	31
Cedar Rapids	Int 33rd Ave Sw & 6th St Sw	99999	99999	498	99999	99999	440	95	33

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Rural	Wb Rmp @ Us 6 Conn To Us 65	99999	99999	99999	99999	99999	99999	52	34
Des Moines	Int Hull Ave & E 14th St	99999	96	91	83	99	80	28	35
Des Moines	Int Se 14th St & Bloomfield Rd	99999	99999	99999	99999	102	45	13	36
Des Moines	Int 50th St & Douglas Ave	99999	70	308	78	96	61	49	37
Davenport	Int Welcome Way & W 53rd St	99999	64	66	52	84	98	56	38
Des Moines	E15th St @ I-235 Wb Ramps/maple	99999	2	9	27	39	23	8	39
Des Moines	Int Douglas Ave & 2nd Ave	99999	245	209	160	233	277	153	39
Des Moines	Int Fm Hubbell Ave & E 33rd St	99999	99999	99999	99999	99999	83	59	41
Des Moines	Int Euclid Ave & Cornell St	99999	90	108	106	65	82	53	42
Des Moines	Int Harding Rd & Hickman Rd	99999	119	281	206	135	200	81	43
Cedar Rapids	Int 1st Ave & Glenbrook Dr to Int Collins Rd & 1st Ave E	99999	99999	99999	99999	99999	99999	100	44
Des Moines	Int University Ave & 2nd Ave	99999	25	44	37	19	14	16	45
Des Moines	Int University Ave & Williams St	99999	46	51	36	27	7	12	46
Urbandale	W Int Douglas Ave & 72nd St	99999	376	262	47	64	22	35	47
Des Moines	Int Fleur Dr & Bell Ave	99999	17	29	64	152	99	83	48
Des Moines	Int 7th St/ Day St/ & I-235 Ramp	99999	258	99999	99999	53	51	88	49
Clinton	Int 19th Ave N & N 2nd Ave	99999	99999	99999	99999	99999	99999	133	50
Council Bluffs	Int N 8th St & W Broadway	99999	93	120	62	104	47	45	51
Cedar Rapids	Int 1st Ave & 19th St Se	99999	99999	99999	316	201	65	55	52
Davenport	Int Kimberly Rd & Eastern Ave	99999	256	111	122	120	72	87	53
Rural	Int Us 61 & Co Y48/110th Ave	99999	150	439	415	305	96	41	54
Des Moines	5th Ave At Ent Ramp To I-235 Eb	99999	61	26	35	57	197	189	55
Des Moines	Int Army Post Rd & Sw 9th St	99999	207	78	109	49	26	44	56
Ottumwa	Int Us 34 & Quincy Ave	99999	99999	99999	99999	166	249	43	57
Des Moines	Int Guthrie Ave & Fm Hubbell Ave	99999	148	404	178	194	172	67	58
Council Bluffs	Ia-192 At Sb I-29 Ramps	99999	99999	99999	99999	99999	121	69	59
Council Bluffs	Int N 16th St & Ave G	99999	39	54	11	4	6	39	60
Sioux City	I-29/us 77 Platform/ Sw Cor	99999	1	3	1	24	13	99	61
Clinton	Lincoln Way/ 17th St To 19th St	168	99999	486	483	367	412	175	62
Des Moines	Jct Us 6 & Us 69	99999	55	79	124	88	44	45	63
Davenport	Int E Locust St & Iowa St	99999	99999	432	147	60	31	108	64
Marshalltown	Int Main St & S 18th Ave	99999	99999	99999	99999	99999	81	73	65
Des Moines	Jct Us 6 & Ia 415	99999	20	32	20	73	250	315	66
Cedar Rapids	Int Wilson Ave & Edgewood Rd Sw	99999	364	201	476	99999	263	128	67
Des Moines	Int Merle Hay Rd & Urbandale Ave	99999	78	130	117	119	64	48	68
Fort Dodge	Int Us 169 & Ave O West	99999	18	17	30	30	43	62	69
Cedar Falls	Int Ia 58 & Greenhill Dr	99999	99999	99999	99999	99999	99999	75	70
Waterloo	Int E San Marnan Dr & Sears St	99999	209	87	164	15	21	51	71
Davenport	Int W Locust St & Washington St	99999	99999	99999	99999	99999	99999	212	72
Indianola	Int Us 65/69 & E Iowa Ave	99999	99999	99999	99999	207	125	70	73
Urbandale	Int Douglas Ave & 109th St	99999	99999	427	99999	99999	99999	141	74
Des Moines	Int Harding Rd & Day St	99999	99999	99999	99999	99999	318	118	75
Des Moines	Se 14th/ Army Post To Cummins Rd	15	84	282	99999	99999	99999	79	76

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Des Moines	Int Euclid & Delaware Av/ne 22nd	99999	4	1	9	7	5	26	77
Des Moines	Int Watrous Ave & Se 14th St	99999	312	77	364	199	84	63	78
Des Moines	Int University Ave & 14th St	99999	300	38	92	145	295	75	79
Mason City	Int Pierce Ave & 19th St Sw	99999	99999	99999	99999	407	379	261	80
Rural	Ia-415@i-35 Wb Ser Rd/nw 49th Pl	99999	97	119	215	423	294	80	81
Le Mars	6th St S& Hawkeye Av/6th Av Sw	99999	99999	99999	99999	99999	99999	886	82
Des Moines	Se 14 St/ Baldwin Ln To Mckinley	99999	99999	99999	99999	38	38	60	83
Davenport	Int W 35th St & Marquette St	99999	127	105	43	56	92	71	84
Rural	Int Us 30 & F Ave/casino Ent	99999	99999	99999	99999	99999	99999	78	85
Des Moines	Int Army Post Rd & S Union St	99999	13	14	2	1	2	19	86
West Des Moines	Grand Ave/ 4th St To 63rd St	266	229	249	190	40	39	61	87
Des Moines	Int High St & 7th St	99999	99999	99999	99999	219	36	27	88
Burlington	Int Division St & Roosevelt Ave	99999	99999	131	410	200	88	64	89
Council Bluffs	24th St/ 27th Ave To 23rd Ave	99999	99999	99999	99999	99999	99999	121	90
Rural	Int Ia 141/state St/co F31/190th	99999	158	219	99999	141	154	92	91
Dubuque	Jct Us 52 & Ia 956	99999	21	63	49	467	301	74	92
Davenport	Int Kimberly Rd & Marquette St	99999	99999	455	244	240	308	84	93
Cedar Rapids	Int Collins Rd & 1st Ave E	99999	99999	99999	99999	99999	393	97	94
Fort Dodge	Int Us 169 & Ave G/a St	99999	91	116	73	99999	387	454	95
Waterloo	Int University Ave & Tunis Dr	99999	99999	243	99999	99999	99999	110	96
Des Moines	Int 19th St & Forest Ave	99999	99999	494	182	150	131	103	97
Council Bluffs	Jct Us 6 & Nb Ia 192	99999	149	370	408	453	117	72	97
Des Moines	Int Fm Hubbellave&e22ndst/sy-int	99999	99999	99999	99999	99999	464	367	99
Davenport	Int W 4th St & Marquette St	99999	222	380	396	455	99999	353	100
Mason City	Int Illinois Ave & 4th St Ne	99999	155	228	170	301	217	171	101
Pleasant Hill	Int Ia 163 & Ne 56th St	99999	99999	99999	99999	99999	99999	145	102
Des Moines	Int Beaver Ave & Urbandale Dr	99999	99999	99999	99999	99999	99999	186	103
Dubuque	Int Penn Ave & J F Kennedy Rd	99999	99999	203	134	89	251	198	104
Waterloo	E San Marnan Dr & Flamming St	99999	164	55	46	144	85	93	105
Des Moines	Int Park Ave & Sw 9th St	99999	99999	99999	113	44	34	138	106
Davenport	Int E 53rd St & Brady St	99999	99999	458	99999	271	142	94	107
Sioux City	Int Sergeant Rd & S Lakeport St	99999	99999	99999	99999	48	42	10	108
Cedar Rapids	Collins Rd/ C Ave Ne To Northlnd	99999	99999	99999	99999	99999	184	107	109
Des Moines	Int Maury St & Se 14th St	99999	225	97	121	82	77	40	110
Des Moines	Int Ingersoll & 31st St	99999	99999	99999	482	265	238	237	111
Des Moines	Int Grand Ave & 63rd St	99999	158	57	308	317	258	90	112
Iowa City	Ia 1 At I-80 Eb Exit Ramp	99999	99999	99999	99999	99999	99999	1533	113
Rural	Int Us 20 & Swiss Valley Rd to Int Us 20 & Co D29/n Cascade Rd	99999	99999	99999	99999	99999	99999	116	114
Cedar Rapids	Blairs Ferry/c Av Ne To Northlnd	99999	99999	433	99999	113	137	106	115
Cedar Falls	Int S Main St Rd & W Ridgewy Ave	99999	99999	99999	99999	99999	99999	253	116
Clinton	Int N 3rd St & 19th Ave N	99999	99999	928	1048	99999	99999	526	117
Oskaloosa	Int A Ave E & N Market St/hwy 63	99999	351	99999	99999	262	165	110	118
Des Moines	Int Clark St & 9th St	99999	255	289	179	216	176	314	119

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Davenport	Int W 5th St & Harrison St	99999	6	4	4	6	20	31	120
Des Moines	Int Woodland Ave & 31st St	99999	217	223	193	350	255	54	121
Burlington	Int Agency St & Roosevelt Ave	99999	63	235	267	134	157	132	122
Boone	Int Story St & Hawkeye Dr	99999	99999	318	139	17	94	125	123
Sioux City	Gr Sep Us 77 Sb Ramps On I-29	99999	99999	99999	99999	99999	99999	912	124
Sioux City	Int Gordon & Nebraska/i-29 Ramp	99999	247	167	305	85	124	88	125
Rural	Us 69 At Eb I-35/80 Ramps	99999	99999	99999	99999	326	162	110	126
Marion	Int 7th Ave & 7th St	99999	331	343	99999	192	111	96	127
Waterloo	Independence/ Bishop To Skyview	99999	99999	99999	99999	99999	99999	192	128
Bettendorf	Gr Sep Wb I-74 @ Ill State Line to I-74 Wb At Ex Ramp To State St	99999	99999	99999	99999	99999	450	375	129
Council Bluffs	Int N 16th St & W Broadway	99999	202	117	99999	174	211	355	130
Ottumwa	Jct Us 63 & Ia 23nb	99999	68	62	79	46	110	119	131
Clinton	Int S 4th St & 7th Ave S	99999	419	320	246	357	354	131	132
Boone	Int Crestwood Dr & Story St	99999	99999	99999	99999	99999	99999	287	133
Muscatine	Int Mulberry Ave & Us 61(x-54)	99999	99999	99999	99999	99999	99999	211	134
Davenport	Kimberly/eastern Av To Spring St	99999	99999	99999	417	99999	431	157	135
Davenport	Int W Locust St & Gaines St	99999	99999	99999	99999	99999	99999	440	136
Coralville	Us 6/ 1st Ave To Rocky Shore	4	3	8	6	21	95	129	137
Des Moines	Eb I235 Ent Ramp At Pennsylvania	99999	99999	99999	151	97	73	194	138
Fort Dodge	Int 5th Ave S & 21st St	99999	406	221	296	54	113	148	139
Clear Lake	Int Us 18/2nd Pl/buddy Holly Pl	99999	99999	500	99999	99999	99999	239	140
Clinton	Int Lincoln Way & 17th St	99999	282	393	255	449	202	139	141
Cedar Rapids	Int 16th Ave Sw & Edgewood Rd Sw	99999	99999	416	99999	235	226	187	142
Des Moines	Int Euclid Ave & Wright St	99999	99999	99999	99999	253	103	109	142
Cedar Rapids	Int 1st Ave & 3rd St W	99999	99999	371	99999	99999	473	342	144
Des Moines	N Int University Ave & 6th Ave	99999	98	94	59	463	272	390	145
Des Moines	Se 14th/ Indianola Rd To Park Av	99999	374	99999	416	109	59	122	146
Des Moines	2nd St At Ent Ramp To I-235 Eb	99999	231	257	275	191	161	115	147
Des Moines	E 15th St @ Ex Ramp Fm I235eb	99999	99999	99999	99999	99999	99999	359	148
Des Moines	Int 19th St & Clark St	99999	36	70	56	237	371	146	149
Davenport	Int 53rd St & Elmore Ave	99999	99999	99999	99999	99999	99999	634	149
Cedar Rapids	Int Mt Vernon Rd & 34th St Se	99999	203	193	152	198	380	232	151
Des Moines	Int Army Post Rd & Se 5th St	99999	252	161	99999	256	163	142	151
Marion	Int Blairs Ferry Rd & Lindale Dr	99999	99999	377	329	105	48	66	153
Indianola	Int Us 65/69 & Ashland Ave	99999	99999	99999	99999	269	291	199	154
Des Moines	Hickman Rd/ 63rd St To 62nd St	99999	99999	99999	99999	99999	99999	134	155
Davenport	Int W River Dr & S Concord St	99999	27	35	418	212	242	86	156
Des Moines	Int E 14th St & Lyon St	99999	99999	99999	155	55	104	130	157
Davenport	Int W River Dr & Stark St	99999	211	327	131	250	119	135	158
Clinton	Int N 3rd St & Main Ave	99999	99999	99999	99999	99999	99999	201	159
Cedar Rapids	Nb I380 Ramps @ Blairs Ferry Rd	99999	99999	402	99999	325	208	222	160
Rural	Int Ia 163 & Ne 70th St	99999	99999	99999	99999	99999	394	391	161
Windsor Heights	63rd St At I-235 Eb Ramps	99999	99999	99999	99999	358	325	137	162

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Marshalltown	Int E Main St & N 3rd Ave	99999	418	276	240	249	229	127	163
Des Moines	Int Walnut St & E 15th St	99999	146	357	381	261	204	113	163
Burlington	Int Market St & Roosevelt St	99999	99999	265	99999	183	239	482	165
Des Moines	Int Grand Ave & 6th Ave	99999	121	184	143	74	74	85	166
Des Moines	Int 31st St & Cottage Grove Ave	99999	115	146	119	99999	99999	218	167
Des Moines	Eint Court Ave & E 15th St	99999	271	100	216	95	56	58	168
Marshalltown	Int W Linn St & S 3rd Ave	99999	99999	99999	99999	99999	99999	361	169
Urbandale	Int Douglas Ave & Nw 86th St to Int Madison Ave & Nw 86th St	99999	99999	99999	99999	99999	177	236	170
Des Moines	Merle Hay Rd/ Douglas To Madison	229	200	286	247	281	170	206	171
Rural	N Jct Us 18 & Us 71/e 44th St	99999	99999	99999	99999	487	126	156	172
Cedar Rapids	Int Us 151 & Wiley Blvd Sw	99999	99999	222	254	175	120	136	173
Cedar Falls	Int Main St & Seerley St	99999	298	353	252	151	149	219	174
Davenport	Int Kimberly(us 6) & Main St	99999	65	150	430	99999	99999	235	175
Cedar Rapids	Int A Ave Ne & 7th St Ne	99999	99999	99999	99999	99999	99999	574	176
Des Moines	Int Grand Ave & 5th Ave	99999	99999	195	107	165	244	212	177
Burlington	Int West Ave & Roosevelt Ave	99999	99999	99999	99999	99999	99999	202	178
Rural	Int Old Us 6 & Co Y14/taylor Ave	99999	99999	99999	99999	99999	99999	147	179
Ames	Int Stang Rd & E 13th St	99999	382	368	384	182	115	216	180
Marshalltown	Int S 6th St & Us 30	99999	99999	99999	99999	475	273	160	181
Ankeny	Int N Ankeny Blvd & Ne 1st St	99999	384	197	368	319	323	154	182
Des Moines	Int Locust Ave & 2nd St	99999	153	153	99999	99999	99999	228	183
Cedar Falls	Int Univ Ave & Rownd St	99999	140	67	301	62	35	24	184
Marion	Jct Us 151 & Ia 13	99999	99999	99999	99999	99999	476	255	185
Centerville	None	99999	99999	99999	99999	399	328	268	186
Davenport	W Locust St/ Clark To Jeben Ave	99999	99999	99999	99999	157	183	177	187
Des Moines	Hubbell/ Easton To J Patterson	99999	190	211	231	111	27	223	188
Rural	Int Us 20 & Mason Ave to Br Us 20 At Lit Sioux Riv	99999	99999	99999	99999	260	105	104	189
Des Moines	Int Kenyon Ave & Sw 9th St	99999	99999	99999	99999	99999	99999	282	190
Cedar Rapids	Int 16th Ave Sw & Wiley Blvd	99999	99999	99999	99999	99999	99999	453	191
Des Moines	Int College Ave & 2nd Ave	99999	99999	99999	99999	112	219	240	192
Waterloo	E San Marnan Dr & La Porte Ave	99999	160	176	269	402	469	144	193
Ames	Int Grand Ave & 6th St	99999	346	269	217	239	300	185	194
Carroll	Int 6th St & Clark St	99999	99999	99999	99999	99999	335	271	195
Rural	Int Ne 22nd St & Broadway Ave	99999	99999	99999	99999	99999	99999	196	195
Des Moines	Int Grand Ave & E 14th St	99999	76	114	259	361	274	163	197
Des Moines	Int Hickman Rd & Merle Hay Rd	99999	12	12	54	101	71	248	198
Mason City	Int 12th St Ne & Federal Ave	99999	99999	99999	99999	99999	99999	252	199
Dubuque	Int 14th St & Locust St	99999	249	145	228	369	429	265	200
Des Moines	Int Crocker St & 12th St	99999	109	115	16	23	75	173	201
Fort Dodge	Int 5th Ave S & 25th St to Int 5th Ave S & 29th St	361	341	273	320	99999	292	294	202
Des Moines	Int Locust Ave & 3rd St	99999	95	217	99999	99999	99999	437	203
Des Moines	Int Ingersoll Ave & Harding Rd	99999	99999	99999	126	143	46	114	204

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Altoona	Int Us 65 & Ne 56th St/hwy 950	99999	185	129	65	148	159	164	205
Cedar Rapids	Int 42nd St Ne & Edgewood Rd	99999	99999	429	99999	99999	99999	274	206
Davenport	Int W C Park Ave & Marquette St	99999	99999	198	86	202	129	172	207
Council Bluffs	Int S 7th St & Willow Ave	99999	99999	99999	99999	99999	99999	191	208
West Des Moines	Int 36th St & University Ave	99999	99999	99999	99999	242	174	220	209
Council Bluffs	Int S 35th St & Nebraska Ave	99999	99999	466	99999	99999	99999	304	210
Bettendorf	Gr Sep Eb I-74 At State Line to I-74eb At Ent Ramp From State St	99999	99999	99999	99999	99999	99999	726	211
Cedar Rapids	Int 29th Ave Sw & Edgewood Rd to Int Wilson Ave & Edgewood Rd Sw	99999	99999	378	205	99999	99999	610	212
Mt. Pleasant	Int Us218 &washington St/hwy 34	99999	99999	99999	99999	99999	99999	233	213
Des Moines	Int Maury St & Se 14th St to Se 14th St Overpass At Yards Rr	99999	99999	99999	99999	99999	99999	959	214
Des Moines	Int Madison Ave & E 14th St	99999	99999	420	332	99999	231	203	215
Des Moines	Int Delaware Ave & Guthrie Ave	99999	99999	99999	99999	356	139	221	216
Davenport	Int W 4th St & Harrison St	99999	72	56	32	99999	99999	370	217
Des Moines	19th St At Ex Ramp From I-235 Wb	99999	99999	99999	99999	279	196	459	218
Dubuque	Jct Us 20 & Ia 966 (old 416) to Int Us 20 & Nw Arterial	99999	99999	99999	99999	373	234	392	219
Davenport	Int W 3rd St & Harrison St	99999	49	23	3	63	116	293	220
Des Moines	Douglas/ Sherman Blvd To Beaver	156	79	71	48	177	360	204	221
Des Moines	Int Meredith Dr & Ia 28	99999	428	307	99999	458	465	247	222
Des Moines	Int Cleveland Ave & E 14th St	99999	99999	400	374	365	377	212	223
Le Mars	Int Us 75 At 12th St S to Int Us 75 & 8th Ave W	99999	99	83	45	14	18	263	224
Coralville	1st Ave/ Us 6 To Clear Cr	234	235	247	439	227	303	166	225
Des Moines	N Int Willowmere Dr & Fleur Dr to Int Fleur Dr & Bell Ave	99999	99999	99999	99999	99999	99999	402	226
Des Moines	Int 35th St & University Ave	99999	99999	99999	99999	99999	99999	381	227
Rural	Int Us 30 & T Ave	99999	99999	99999	99999	99999	99999	5703	228
Ames	Int Beach Ave & Lincoln Way	99999	99999	342	99999	459	284	178	229
Des Moines	Int Indianola Ave & Se 14th St	99999	189	64	169	61	28	38	230
Davenport	Int E 4th St & Pershing St	99999	99999	99999	99999	99999	276	297	231
Ankeny	Int S Ankeny Blvd & Peterson Dr to Int S Ankeny Blvd & Se 3rd St	99999	99999	373	276	90	179	279	232
Des Moines	Harding Rd/ Hickman To Bennett	87	51	69	5	276	303	336	233
Mason City	Int 15th St Se & Federal Ave	99999	320	190	176	99999	446	205	234
Clive	Int 42nd St & University Ave to Int 36th St & University Ave	99999	99999	99999	99999	99999	99999	411	235
Cedar Rapids	Int Blairs Ferry Rd & Council St	99999	99999	99999	99999	99999	99999	324	236
Clive	Int Hickman Rd & 104th St to Int Us 6 & Nw 100th St	99999	99999	99999	99999	99999	99999	272	237
Mt. Pleasant	Int Washington St & Jefferson St	99999	99999	99999	99999	344	230	197	238
Des Moines	Int Merle Hay Rd & Aurora Ave	99999	173	175	177	299	100	250	239
Rural	Int Ia 220 & A St (middle Amana) to Int Ia 220 & B St (high Amana)	99999	99999	99999	99999	99999	314	326	240
Des Moines	Int Harding Rd & University Ave	99999	99999	99999	424	222	164	351	241
Sioux City	Int Hamilton Blvd & Tri View Ave	99999	99999	99999	99999	99999	286	179	242
Des Moines	Int Washington Ave & E 14th St	99999	197	104	72	284	499	291	243

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Cedar Rapids	Edgwd Rd At E-w Ramp To Edgwd Dr to Int Ellis Rd & Edgewood Rd Nw	99999	99999	99999	99999	99999	99999	243	244
Des Moines	Int 42nd St & University Ave	99999	397	106	150	50	194	50	245
Des Moines	Int Mckinley Ave & Sw 21st St	99999	99999	410	399	184	409	327	246
Ames	Int S Walnut Ave & S 3rd St	99999	99999	99999	99999	415	297	225	247
Rural	Int Us 75 & Co C38	99999	99999	99999	99999	99999	99999	338	248
Davenport	Int W 3rd St & N Division St	99999	111	81	210	473	487	174	248
Davenport	Int Us 6 & N Division St	99999	162	132	171	195	418	258	250
West Des Moines	Int Westown Pkwy & 35th St to 35th St At I-235 Wb Ramps	99999	99999	99999	99999	99999	99999	373	251
Des Moines	Int Locust Ave & 6th Ave	99999	99999	99999	116	106	68	216	251
Clive	Int Nw 100th St & University Ave to Int Clark St & Nw 100th St	99999	99999	99999	99999	99999	99999	561	253
Des Moines	Int Harding Rd & Douglas Ave	99999	186	5	23	34	58	158	254
Ames	Int Elwood Dr & Lincoln Way	99999	99999	99999	99999	99999	99999	480	255
Cedar Rapids	Int Ia 922 & Edgewood Rd	99999	99999	99999	99999	99999	99999	734	256
Council Bluffs	24th St At Nb I-29 Ramps to Int 24th St & 27th Ave	340	99999	99999	99999	99999	99999	528	257
Urbandale	Int Nw 86th St & Iltis Dr to Int Meredith Dr & Nw 86th St	99999	99999	99999	99999	99999	99999	873	258
Fort Dodge	Int Us 20 & Ave C	99999	99999	99999	99999	99999	99999	1057	259
Davenport	Int W 49th St & N Pine St	99999	260	340	99999	99999	99999	1108	260
Dubuque	Sb Us 52/61/151 Ramp @ W 4th St	99999	424	99999	221	156	146	209	261
Marshalltown	Int W Church St & S Center St	99999	99999	99999	99999	411	404	404	261
Burlington	Int Sunnyside Ave/roosevelt Ave	99999	99999	99999	99999	99999	99999	959	263
Davenport	Kimberly Rd Ovrps At Cmstp&p Rr to Int Kimberly Rd & Eastern Ave	99999	99999	99999	99999	352	197	226	264
Des Moines	Int Woodland Ave & Harding Rd	99999	107	233	157	99999	99999	461	265
Fort Dodge	Int 1st Ave S & 15th St	99999	332	261	213	187	215	158	266
Sioux City	Int W 28th St & Hamilton Blvd	99999	99999	477	99999	395	491	310	267
Urbandale	Int Douglas Ave & 70th St	99999	317	190	105	29	54	161	268
Cedar Falls	Sb Ia 58 Ramps @ Univ Ave	99999	99999	99999	99999	99999	99999	729	269
Urbandale	Int Douglas Ave & Nw 86th St	99999	99999	316	458	459	99999	303	270
Davenport	Int E 35th Ct & Elmore Ave to None	99999	99999	99999	99999	99999	99999	518	270
Coralville	Int 7th St & 1st Ave to Int 9th St & 1st Ave	99999	99999	99999	99999	472	227	740	272
Davenport	Int W 2nd St & Warren St	99999	99999	99999	471	72	212	267	273
Des Moines	Int Keo Way & Crocker St	99999	99999	99999	438	99999	221	251	274
Burlington	Int Mt Pleasant St/roosevelt Ave	99999	210	421	99999	99999	423	451	275
Des Moines	Int School St & 3rd St	99999	192	445	99999	37	62	229	276
Council Bluffs	None to Int Nebraska Ave & 23rd Ave	99999	99999	99999	99999	99999	99999	292	277
Bettendorf	Int Middle Rd & Aaa Court to Int Devils Glen Rd & Middle Rd	99999	99999	99999	99999	99999	99999	357	278
Davenport	Int E 35th St & Northwest Blvd	99999	99999	99999	99999	99999	493	389	279
Spencer	Int E 18th St & N Grand Ave	99999	99999	387	398	99999	99999	463	280
Oskaloosa	Int C Ave E & N Market St	99999	99999	99999	99999	99999	411	341	281
Des Moines	Int Harding Rd & Forest Ave	99999	22	24	110	203	213	150	282
Des Moines	Int Army Post Rd/sw 21st/fleur D	99999	99999	99999	99999	99999	99999	345	283

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Sioux City	Int W 4th St & Hamilton Blvd	99999	99999	372	99999	99999	346	350	284
Ames	Int Welch Ave & Lincoln Way	99999	29	20	378	99999	439	283	285
Cedar Rapids	Int Ia 100 & E Ave to Int Collins Re & C Ave Ne	99999	99999	99999	99999	99999	99999	312	286
Iowa City	Int Gilbert St & Jefferson St	99999	99999	99999	99999	99999	99999	383	287
Sioux City	Int Lewis Blvd & 41st St	99999	349	306	313	425	99999	295	288
Waterloo	Int Ansborough Ave & Univ Ave	99999	99999	468	99999	384	353	190	289
Davenport	Int Kimberly Rd & Mississippi Av to Int Us 6 & Bridge Ave	99999	99999	99999	99999	99999	99999	697	290
Davenport	Int E 53rd St & Jersey Ridge Rd	99999	99999	99999	99999	390	284	521	291
Cedar Rapids	Edgewood Rd/ Johnson To E Ave Nw	99999	99999	99999	99999	193	132	195	292
Cedar Rapids	Int 29th St Dr Se & 1st Ave	99999	82	252	375	99999	99999	558	293
Urbandale	Ia 28 At I-35 Eb Ramps	99999	99999	99999	99999	99999	99999	334	293
Waterloo	Int W Ridgeway Ave & Sergeant Rd	99999	99999	293	220	427	99999	269	295
Waterloo	Int Nb Us 218 & W 11th St	99999	99999	99999	99999	99999	99999	408	296
Rural	Jct Us 71 & Ia 3	99999	99999	99999	99999	140	205	91	296
Cedar Rapids	Collins Rd/ Northland To Lindale	99999	99999	99999	99999	99999	99999	184	298
Estherville	Int Central Ave & 9th St	99999	243	300	299	99999	99999	653	299
Council Bluffs	Big Lake Rd At Ic Rr	99999	99999	99999	99999	99999	99999	596	300
Des Moines	Int Douglas Ave & Fm Hubbell Ave to Int Douglas Ave & E 37th St	99999	99999	99999	453	99999	99999	530	301
Rural	Int Us 6 & Scott Blvd/sioux Ave	99999	99999	99999	99999	99999	99999	4020	302
Cedar Rapids	Nb I-380 Ramp At Eb Ia 100 Ramp	99999	145	99999	338	99999	99999	278	303
Ottumwa	W Jct Us 34 & Us 63 to Int Us 34 & Quincy Ave	99999	99999	99999	99999	190	99999	938	304
Rural	Int Us 20 & Madison Ave to Int Us 20 & 235th St	99999	99999	99999	99999	99999	99999	644	305
Boone	Int Eisenhower Ave & N Story St	99999	99999	99999	99999	99999	99999	275	306
Davenport	Int W Locust St & N Lincoln Ave	99999	99999	99999	99999	99999	99999	793	307
Ames	Int Grand Ave & 20th St	99999	99999	99999	99999	99999	99999	346	308
Rural	Co V56 At Iowa Co Line to Int Co E68 & Co V56	99999	99999	99999	99999	99999	99999	357	309
Johnston	Int Nw 86th St & Nw 62nd Ave Cen	99999	99999	99999	99999	99999	99999	524	310
Council Bluffs	Int 23rd Ave & S 24th St to Int Nebraska Ave & 23rd Ave	99999	354	414	446	99999	108	257	311
Mason City	Int Us 18 & Pierce Ave	99999	44	52	141	315	207	398	312
Marshalltown	Int S Center St & Us 30/hwy 14 to Int Us 30 & Governor Rd/smith Av	99999	99999	99999	99999	99999	99999	318	313
Davenport	Int Us 6 & N Pine St	99999	99999	99999	99999	464	402	298	314
Waterloo	Int E Ridgeway Ave & W 9th St	99999	99999	99999	99999	99999	99999	604	315
Ottumwa	N Int Us 63 & Kitterman/4th St	99999	130	100	357	234	240	208	316
Urbandale	Int Douglas Ave & State Farm Rd	99999	99999	99999	99999	99999	99999	378	317
Mason City	Us 18/brairstone Dr/grover Ave to Us 18 & Winnebago Way/cerro Gord	99999	99999	99999	99999	99999	99999	287	318
Mason City	Int Illinois Ave & 4th St Ne to W Int Birch Dr & 4th St Se	99999	288	330	99999	99999	243	764	319
Iowa City	Int Gilbert St & Kirkwood Ave	99999	268	248	125	210	180	188	320
Rural	Jct Us 151/ia 13 & Ia 100	99999	99999	99999	99999	264	109	301	321
Rural	Int Ia 281 & Co V49/raymond Rd	99999	192	192	404	275	352	682	322
Ankeny	Int Ne Trilein Dr & Ne 1st St to Int Ne Hayes Dr & E 1st St	99999	99999	99999	99999	99999	99999	347	323

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Williamsburg	Ia-149 At I-80 Eb Ramps	99999	99999	99999	99999	99999	99999	409	324
Oelwein	Int Ia 150 & 7th St Se	99999	99999	99999	99999	99999	99999	170	325
Humboldt	Ia 3& Taft St/jerry Hatcher Rd	99999	99999	99999	99999	99999	99999	664	326
Rural	Int Us 59 & Arrowhead Rd	99999	99999	99999	99999	99999	151	284	327
Urbandale	Int Douglas Ave & 75th St	99999	138	155	146	388	313	394	327
Iowa City	Sb Us 218 Ramps At Ia 1	99999	99999	99999	99999	99999	99999	599	329
Des Moines	Sint Railroad Ave & Se 14th St	99999	99999	99999	99999	99999	99999	183	329
Council Bluffs	Int 32nd Ave & Piute	99999	99999	99999	99999	99999	99999	143	331
Cedar Rapids	Int Collins Rd & Twixtown Rd Ne	99999	99999	99999	99999	99999	99999	382	332
Rural	Int Us 69 & Oakwood St to Int Us 69 & Co R50/pacific St	99999	99999	99999	99999	159	386	843	333
Dubuque	Int Us 20 & Wacker Dr to None	99999	99999	99999	99999	99999	99999	545	334
Des Moines	Int E 30th St & Grand Ave	99999	195	166	140	185	167	238	335
Rural	Jct Us 61 & Ia 2 (w)	99999	99999	99999	99999	99999	99999	308	336
Dubuque	Int Us 20 & Nw Arterial	99999	99999	302	390	99999	389	527	337
Des Moines	Int Grand Ave & Terrace Rd to Int Grand Ave & 19th St	99999	99999	99999	99999	99999	160	215	337
Council Bluffs	Ridge St/n Broadway	99999	99999	99999	99999	99999	99999	559	339
Des Moines	Int Walnut St & E 14th St	99999	204	401	268	99999	99999	525	340
Coralville	Int 6th Ave & Us 6 to Int Us 6 & 10th Ave	207	99999	99999	159	176	190	637	341
Des Moines	Army P0st Ent To Southridge Mall	99999	14	19	50	81	254	328	341
Cedar Rapids	Int Mt Vernon Rd & 40th St Se to Int Mt Vernon Rd & 42nd St Se	99999	99999	99999	99999	99999	99999	566	343
Ottumwa	Int Us 63 & Elmdale Ave	99999	48	30	31	35	63	151	344
Davenport	E 53rd St At Wb I-74 Ramps	99999	99999	99999	99999	99999	500	330	345
Des Moines	Int 63rd St & University Ave	99999	184	136	96	99999	391	363	346
Davenport	Int E 53rd St & Lorton Ave	99999	99999	99999	99999	99999	99999	915	347
Des Moines	Int 6th Ave & School St	99999	234	99999	99999	99999	99999	660	348
Des Moines	Int Euclid Ave & E 25th St	99999	99999	99999	497	154	89	313	348
Cedar Rapids	Int 3rd Ave Sw & 6th St Sw	99999	99999	99999	203	152	57	325	350
Cedar Rapids	Int Us 30 & 218 & Edgewood Rd	99999	99999	99999	99999	99999	99999	770	351
Cedar Rapids	Int Collins Re & C Ave Ne	99999	99999	99999	99999	296	223	280	352
Grinnell	Int 6th Ave & West St/hwy 6	99999	99999	99999	99999	99999	99999	610	353
Des Moines	Int Ingersoll Ave & 27th St to Int Ingersoll Ave & 24th St	99999	99999	99999	99999	99999	99999	302	354
Cedar Rapids	None to Int Us 151 & Wiley Blvd Sw	99999	99999	99999	99999	99999	259	343	355
Burlington	Us 61 At Wb Us 34 Ramps	99999	99999	99999	99999	99999	99999	800	356
Des Moines	Int Army Post Rd & Se 3rd St to Int Army Post Rd & Se 5th St	99999	99999	99999	99999	99999	481	541	357
Des Moines	Int Center St & 7th St	99999	99999	99999	99999	99999	99999	343	358
Des Moines	Int Park Ave & Se 14th St to None	99999	99999	99999	99999	469	408	320	359
Des Moines	Int Harding Rd & Hickman Rd to Int 18th St & Hickman Rd	99999	99999	99999	99999	99999	99999	2048	360
Iowa City	Int Ia 1 & Orchard St to Int Ia 1 & Riverside Dr	99999	99999	99999	99999	99999	99999	332	361
Des Moines	E Jct Ia 5 & Ia 28/sw 42nd St	99999	99999	99999	99999	99999	99999	399	361
Des Moines	Int Center St & W River Dr	99999	99999	99999	99999	293	302	263	363

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Des Moines	Int Euclid Ave & 6th Ave	99999	124	140	138	339	348	319	364
Des Moines	31st St At I-235 Wb Ramps	99999	99999	99999	99999	99999	99999	625	365
Rural	Int Aurora Ave & E 14th St	99999	88	46	53	94	122	266	366
Cedar Rapids	Int Susan Dr & Edgewood Rd to Int Johnson Ave & Edgewood Rd	99999	99999	99999	99999	99999	99999	497	367
Rural	None to Int Jf Kennedy Rd & Central Ave	99999	99999	99999	99999	99999	99999	420	368
Rural	I-80 Eb At Ent Loop From I-380sb	99999	99999	99999	99999	331	280	411	369
West Des Moines	Int 36th St & University Ave to Int Nw 100th St & University Ave	99999	99999	99999	99999	99999	99999	483	370
Des Moines	Jct Us 6 & Ia 28	99999	99999	99999	99999	142	260	590	371
Bettendorf	Int Lincoln Rd & Kimberly Rd	99999	99999	99999	99999	99999	99999	504	372
Davenport	Int Kimberly Rd & Brady St	99999	99999	464	295	254	333	328	373
Muscatine	Int Us 61 By Pass & Grandview Av	99999	99999	99999	99999	99999	99999	585	374
Des Moines	Int Ingersoll & 35th St	99999	372	99999	99999	362	316	422	375
Des Moines	Int Grand Ave & 42nd St	99999	99999	99999	278	42	32	784	376
Waterloo	Int W Parker St & Broadway St	99999	99999	443	99999	266	378	549	377
Des Moines	N Int Franklin Ave & 2nd Ave	99999	99999	99999	99999	99999	419	493	378
Des Moines	Int Ingersoll Ave & 28th St to Int Ingersoll Ave & 27th St	99999	99999	99999	99999	258	255	365	379
Sioux City	Int Stone Ave & Gordon Dr	99999	99999	99999	99999	99999	99999	606	379
Cedar Rapids	Int 1st Ave & 18th St West	99999	99999	99999	99999	99999	99999	836	381
Cedar Rapids	Int 1st Ave & 10th St E	99999	99999	99999	99999	99999	455	406	382
Sioux City	Int Gordon & Pierce/i-29 Ramp	99999	415	99999	99999	99999	99999	555	383
Des Moines	Int Carpenter Ave & 19th St	99999	371	341	354	99999	99999	1475	384
De Witt	Int Us 30 & 11th Ave	99999	99999	99999	99999	99999	99999	462	385
Dubuque	Int Penn Ave & J F Kennedy Rd to Int Carter Rd & J F Kennedy Rd	99999	99999	99999	99999	99999	99999	397	386
West Des Moines	35th St At I-235 Wb Ramps	99999	276	313	219	154	128	317	386
Cedar Falls	Univ Ave & Black Hawk Village	99999	99999	474	99999	167	148	473	388
West Des Moines	Int Westown Pkwy & 22nd St	99999	208	143	148	479	99999	403	389
Davenport	Int Us 61 & 42nd St to S Int E 46th St & Brady St	295	315	99999	99999	430	279	417	390
Iowa City	Int Riverside Dr & Riverside Ct to Int Riverside Dr & Myrtle Ave	99999	99999	99999	99999	99999	99999	814	391
Mason City	Int Us 18 & Taft Ave	99999	99999	99999	99999	99999	99999	550	392
Ames	Int Lincoln Way & Sheldon Ave	99999	133	467	99999	99999	438	269	393
Sioux Center	Int 9th St Sw & Main Ave	99999	99999	99999	99999	99999	99999	494	394
Ottumwa	Br Us 63 At Dm Riv	99999	99999	99999	99999	99999	99999	649	394
Muscatine	Int Harrison St & Park Ave	99999	99999	99999	99999	99999	175	446	396
Sioux City	Int 6th St & Hoeven Dr	99999	186	253	258	132	53	577	397
Des Moines	Int University Ave & 56th St	99999	99999	99999	99999	206	182	230	398
Davenport	Int W Locust St & Harrison St	99999	99999	99999	99999	99999	321	231	398
Cedar Rapids	Int Us 218 & Stony Point Rd Sw	99999	99999	99999	99999	99999	99999	807	400
Cedar Rapids	Int 51st St & Center Point Rd	99999	99999	99999	99999	99999	99999	364	401
Clinton	Int N 2nd St & 13th Ave N	99999	99999	99999	99999	99999	99999	281	402
Cedar Falls	Int Univ Ave & Adams St	99999	99999	99999	99999	99999	237	354	403
Waterloo	Int Burton Ave & Broadway St	99999	99999	99999	99999	99999	99999	556	403

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Iowa City	Int Van Buren St & Burlington St	99999	99999	99999	99999	99999	99999	457	405
Clinton	Int S 14th St & Harrison Dr	99999	99999	828	730	133	428	507	406
Cedar Rapids	Int Johnson Ave & 18th St Nw	99999	99999	99999	99999	99999	99999	1139	407
Marion	Int Us 151 & 22nd St to Int Us 151 & 25th St	99999	99999	99999	99999	99999	495	323	408
Ames	Lincoln Way& Clark Av/walnut	99999	99999	99999	99999	99999	99999	429	409
Rural	Int Ia 281 & Old Us 20	99999	99999	99999	99999	99999	99999	1240	410
Des Moines	Int Locust Ave & 7th St	99999	425	99999	99999	99999	99999	315	411
Clive	None	99999	99999	99999	99999	99999	99999	537	412
Clinton	Int S 3rd St & 2nd Ave S	99999	99999	99999	99999	99999	99999	639	413
Marshalltown	Int Ia 14 & Nicholas Dr	99999	99999	99999	99999	99999	336	424	414
Rural	Int Us 218 & Easton to Int Us 218 & 250th	99999	99999	99999	99999	99999	99999	620	415
Cedar Rapids	Int 1st Ave & 4th St Nw & L St	99999	99999	389	99999	99999	330	234	416
Marshalltown	Int E Anson St & S 18th Ave	99999	99999	99999	99999	99999	99999	496	417
Ottumwa	Int Myrtle St (ramp) & Bardell	99999	99999	99999	99999	99999	99999	1135	418
Fort Dodge	Int Us 169 & Ave O West to Int Us 169 & Ave G/a St	99999	99999	99999	99999	99999	99999	1347	419
Altoona	Int 9th St Nw & Us 6/65	99999	99999	99999	99999	387	253	805	420
West Des Moines	I-80 Wb At Ramp From I-35 Sb to I-35 Sb At Ramp To I-80 Wb	99999	99999	99999	99999	99999	99999	759	421
Windsor Heights	8th St At Exit From I-235eb	99999	426	99999	99999	335	228	417	422
Clive	Merge Location to Us 6 At Sb I-35/80 Ramps	99999	99999	99999	99999	99999	99999	371	423
Ottumwa	Int Us 63 & Rochester Ave	99999	99999	172	112	203	343	576	424
Davenport	Int Us 6 & Elmore Ave	99999	99999	99999	99999	291	452	193	425
Cedar Rapids	Int C Ave Ne & Blairs Ferry Rd	99999	99999	99999	99999	343	187	432	426
Davenport	Int Us 6 & N Division St to Int Us 6 & Sturdevant St	99999	99999	99999	99999	99999	99999	497	427
Iowa City	Int Us 6 & Sycamore St	99999	99999	99999	99999	118	99999	602	428
Des Moines	Int Park Ave & Fleur Dr	99999	178	183	99999	348	441	305	429
Fort Madison	Int Ave L & 34th St	99999	99999	99999	99999	99999	99999	1115	430
Burlington	Int Angular St & Summer St	99999	99999	99999	99999	99999	99999	471	431
Rural	Int 151 & 6th St	99999	99999	99999	99999	99999	99999	1200	432
Cedar Rapids	Int Waconia Ave & 6th St Sw	99999	253	99999	99999	99999	99999	388	433
Des Moines	W Int Guthrie Ave & Dixon St	99999	99999	99999	99999	99999	99999	226	434
Cedar Rapids	Int Mtvernon Rd & Memorial Dr Se	99999	99999	99999	99999	99999	99999	554	435
Marion	Int 44th St & Us 151	99999	99999	99999	99999	99999	99999	499	436
Des Moines	Int Beaver Ave & Madison Ave	99999	92	61	71	25	100	168	436
Rural	Us 218 @ Co G36/220th St	99999	99999	99999	99999	99999	99999	1895	438
Des Moines	Int Vine St & 1st St to Int Grand Ave & 63rd St	99999	99999	99999	99999	99999	99999	999	439
Des Moines	Int Grand/ Locust & Fleur Dr	99999	361	99999	99999	126	143	181	440
Des Moines	Int Crocker St & 5th Ave	99999	99999	99999	99999	99999	99999	705	441
Cedar Rapids	Int Ia 100 & Council St	99999	99999	99999	99999	99999	99999	559	442
Iowa City	Int Governor St & College St	99999	99999	99999	345	397	436	543	443
Creston	Int Sumner Ave & Adams St	99999	99999	99999	99999	99999	99999	495	444
Milford	Int 13th St & Okoboji Ave/a34	99999	99999	99999	99999	99999	150	507	445
Dubuque	Int W 17th St & Madison St	99999	394	1059	99999	99999	99999	504	446

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Coralville	Int Us 6 & 2nd Ave to Br Us 6 At Clear Crk	99999	99999	99999	317	99999	398	502	447
Iowa City	Int Mormon Trek Rd & W Benton St to None	99999	99999	99999	99999	99999	99999	835	448
Davenport	Int Welcome Way & 46th St	99999	99999	99999	99999	99999	334	425	449
Rural	Int Ne 51st Ave 14th St	99999	99999	99999	99999	489	265	470	450
Ankeny	Int Ne Delaware Ave & Ne 1st St	99999	99999	99999	99999	99999	99999	410	451
Clinton	Int S 3rd St & 5th Ave S to Int S 2nd St & 5th Ave S	99999	99999	99999	99999	99999	99999	415	452
Cedar Rapids	Int 33rd Ave Sw & Edgewood Rd	99999	99999	99999	99999	99999	99999	648	452
Windsor Heights	Br Wb I-235 At Walnut Crk to I-235 Wb At Ent Ramp From 63rd	99999	99999	99999	99999	99999	99999	1778	452
Rural	Int Us 30 & F Ave/casino Ent to Int Us 30 & E Ave N	99999	99999	99999	99999	481	107	260	452
Waterloo	Int Sarah Dr & Flamming Dr	99999	99999	99999	99999	99999	99999	616	456
Cedar Rapids	Int C Ave Ne & Blairs Ferry Rd to Blairs Ferry Rd At Cmstp&p Rr	99999	99999	99999	99999	99999	99999	456	457
West Des Moines	Int 36th St & Westown Pkwy to Int Westown Pkwy & 35th St	99999	359	294	175	408	99999	970	457
Iowa City	Int Us 6 & Keokuk St	99999	392	99999	99999	99999	99999	564	459
Des Moines	N Int University Ave & 6th Ave to Int Indiana Ave & 6th Ave	374	99999	514	333	296	209	311	460
Cedar Rapids	Int 1st Ave & 3rd St E	99999	99999	438	280	99999	99999	466	461
Urbandale	Br Nw 86th St @ Walnut Crk to None	99999	99999	99999	99999	99999	99999	485	461
Des Moines	Int Polk Blvd & Center St	99999	99999	99999	99999	99999	99999	1954	463
Des Moines	Int Locust Ave & E 6th St	99999	99999	99999	358	131	166	207	464
Dubuque	Int Wacker Dr & J F Kenndy Rd	99999	99999	99999	99999	99999	99999	356	465
Iowa City	Int Johnson St & Jefferson St	99999	99999	99999	99999	99999	99999	469	466
Ankeny	Int Sw School St & Nw 1st St	99999	99999	1466	1462	547	99999	1055	466
West Des Moines	86th St/ Westown Pkw To Universi	355	74	98	120	99999	99999	568	468
Clinton	Int Manufacturing Dr & S 19th St	99999	99999	99999	99999	99999	99999	552	469
Des Moines	Int E Army Post Rd & Se 14th St to Int Army Post Rd & Se 16th St	99999	99999	99999	99999	99999	99999	427	470
Sioux City	Int 14th St & Nebraska St	99999	77	68	41	138	99999	365	471
Rural	Int Ia 9 & 360th Ave W to Int Ia 9/co N22/340th Ave/c L	99999	99999	99999	99999	99999	99999	928	472
Cedar Rapids	Int 1st Ave & 13th St E/ct Pt Rd	99999	99999	99999	99999	99999	99999	578	473
Le Mars	Int Plymouth St& 5th Ave W/hwy 3	99999	99999	99999	99999	421	364	691	473
Ames	Int Grand Ave & 13th St	99999	99999	99999	99999	99999	99999	436	473
Rural	Int Us 52 & Boy Scout Rd to Int Us 52 & Fettkether Ln	150	196	266	99999	489	99999	426	476
Des Moines	Int Grand Ave & 56th St to Int Grand Ave & 51st St	99999	99999	99999	99999	99999	99999	517	476
Council Bluffs	Broadway(us 6) Over Ccp Rr to Int N 8th St & W Broadway	99999	99999	99999	99999	99999	99999	407	478
Council Bluffs	Int Us 6 & North Ave	99999	87	60	55	68	66	262	479
Davenport	Int W River Dr & Marquette St	99999	99999	99999	99999	99999	99999	797	480
Ankeny	Int Ne Hayes Dr & E 1st St to Int Ne Delaware Ave & Ne 1st St	99999	99999	99999	99999	99999	99999	1215	481
Sioux City	Int W 7th St & Hamilton Blvd	99999	99999	99999	99999	99999	99999	439	482
Rural	None to Int Us 18 & Co S34/lark Ave	99999	99999	99999	99999	99999	99999	1375	483
Rural	Int Hickman Rd & 73rd St	99999	350	416	99999	99999	399	435	484

Table B.1. (continued)

City	Literal Description	85_89	86_90	87_91	88_92	91_95	92_96	94_98	95_99
Des Moines	Int Post St & Douglas Ave to Int 30th St & Douglas Ave	99999	99999	99999	99999	147	310	487	485
Indianola	Int Us 65/69 & Euclid Ave	99999	99999	99999	99999	99999	99999	547	486
Council Bluffs	Int S Omaha Bridge Rd &s 35th St to None	99999	267	160	136	107	86	369	487
Des Moines	Int Grand Ave & 7th St	99999	99999	99999	428	238	261	419	488
Des Moines	Int Ovid Ave & 2nd St	99999	99999	99999	99999	99999	99999	450	489
Windsor Heights	At Rancho Grande Blvd Fm Ne Ramp	99999	375	99999	99999	43	39	224	490
Sioux City	Int 19th St & Floyd St	99999	99999	99999	99999	99999	99999	709	491
Iowa City	Int Ia 1 & Mormon Trek Blvd	99999	99999	99999	224	360	188	167	492
Sioux Center	Int 3rd St Ne & S Main Ave	99999	99999	99999	99999	99999	99999	687	493
Iowa City	Int Mormon Trekblvd& Melrose Ave	99999	118	152	238	286	305	458	494
Bettendorf	Int Devils Glen Rd & Middle Rd	99999	99999	99999	99999	99999	99999	478	495
Dubuque	Int 5th St & White St	99999	99999	99999	99999	99999	489	532	496
Cedar Rapids	Int Ia 922 & Westdale Dr	99999	99999	99999	99999	99999	99999	1185	497
Des Moines	Int Mckinley Ave & Se 14th St	99999	99999	99999	99999	229	138	244	498
Davenport	Int W 53rd St & Sheridan St to Int Welcome Way & W 53rd St	99999	99999	99999	99999	99999	99999	934	499
Cedar Falls	Int 18th St & Hudson Rd	99999	99999	99999	99999	99999	99999	771	500

APPENDIX C. AMES/DES MOINES INTERSECTION PAST RANKINGS

Each of the 1031 intersections used in this research have a ranking history. Many have been ranked highly, some have never been ranked within the top 10,000 sites (i.e., they have never met the one fatal crash, four injury crashes, or 8 total crashes initial criteria). The rankings for these 1031 intersections are shown in Table C.1., which is sorted by frequency of 1998 crashes (not shown).

Table C.1. 15-year rankings for 1031 intersections

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
11	Des Moines	US 69/SE 14th St and Park Ave	0	27	2	12	8	10	4	6
5020	Ames	Duff Ave. and S 16th Ave	0	0	0	0	0	0	30	15
117	Des Moines	E 30th St and IA 163/University Ave	0	205	162	81	52	24	22	17
53	Des Moines	2nd Ave and Holcomb Ave	0	52	47	39	87	214	14	18
5066	Ames	Grand and Lincoln Way	0	0	0	449	0	367	169	22
139	Des Moines	E 21st St and IA 163/University Ave	0	103	39	100	108	233	65	30
58	Des Moines	US 69/E 14th St and Hull Ave	0	96	91	83	99	80	28	35
272	Des Moines	US 69/E 15th St and Maple St	0	2	9	27	39	23	8	39
69	Des Moines	IA 415/2nd Ave and Douglas Ave	0	245	209	160	233	277	153	39
97	Des Moines	2nd Ave and University Ave	0	25	44	37	19	14	16	45
119	Des Moines	Williams St and IA 163/University A	0	46	51	36	27	7	12	46
22	Des Moines	Fleur Dr and Bell Ave	0	17	29	64	152	99	83	48
278	Des Moines	7th St and Day St/I-235 WB	0	258	0	0	53	51	88	49
25	Des Moines	SW 9th St and Iowa 5/Army Post Road	0	207	78	109	49	26	44	56
160	Des Moines	Hubbell Ave and Guthrie Ave	0	148	404	178	194	172	67	58
70	Des Moines	IA 415/2nd Ave and US 6/Euclid Ave	0	20	32	20	73	250	315	66
146	Des Moines	US 6/Merle Hay Rd and US 6/Urbandale Ave	0	78	130	117	119	64	48	68
18	Des Moines	US 69/SE 14th St and IA 5/Army Post Rd	15	84	282	0	0	0	79	76
164	Des Moines	Delaware Ave and US 6/Euclid Ave	0	4	1	9	7	5	26	77
294	Des Moines	2nd Ave and I-80 WB	0	97	119	215	423	294	80	81
29	Des Moines	South Union/Chaff and Iowa 5/Army Post Road	0	13	14	2	1	2	19	86
202	Des Moines	7th St and High St	0	0	0	0	219	36	27	88
125	Des Moines	W 19th St and Forest Ave	0	0	494	182	150	131	103	97
121	Des Moines	Hubbell Ave and IA 163/University Ave	0	0	0	0	0	464	367	99
145	Des Moines	Beaver Ave and Urbandale Ave	0	0	0	0	0	0	186	103
15	Des Moines	SW 9th St and Park Ave	0	0	0	113	44	34	138	106
100	Des Moines	6th Ave and University Ave	0	98	94	59	463	272	390	145
275	Des Moines	2nd Ave and I-235 EB On-Ramp/School St.	0	231	257	275	191	161	115	147
271	Des Moines	US 69/E 15th St and I-235 EB On/Off-Ramp	0	0	0	0	0	0	359	148
126	Des Moines	W 19th St and Clark St	0	36	70	56	237	371	146	149
27	Des Moines	SE 5th St and Iowa 5/Army Post Road	0	252	161	0	256	163	142	151
273	Des Moines	US 69/E 14th St and I-235 EB Off-Ramp	0	0	0	155	55	104	130	157
288	Des Moines	IA 28/63rd St and I-235 EB	0	0	0	0	358	325	137	162
191	Des Moines	US 69/E 15th St and Walnut Ave	0	146	357	381	261	204	113	163
232	Des Moines	6th Ave and Grand Ave	0	121	184	143	74	74	85	166
94	Des Moines	IA 28/Merle Hay R and US 6/Douglas Ave	229	200	286	247	281	170	206	171

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
257	Des Moines	5th St and Grand Ave	0	0	195	107	165	244	212	177
5172	Ames	Stange Rd. and 13th St.	0	382	368	384	182	115	216	180
261	Des Moines	2nd Ave and Locust St	0	153	153	0	0	0	228	183
1212	Des Moines	SW 9th St and Kenyon Ave	0	0	0	0	0	0	282	190
96	Des Moines	2nd Ave and College Ave	0	0	0	0	112	219	240	192
5079	Ames	Grand and 6th St.	0	346	269	217	239	300	185	194
82	Des Moines	IA 28/Merle Hay R and US 6/Hickman Rd	0	12	12	54	101	71	248	198
268	Des Moines	3rd St and Locust St	0	95	217	0	0	0	437	203
41	Des Moines	M.L. King Jr Pkwy and Ingersoll Ave	0	0	0	126	143	46	114	204
56	Des Moines	US 69/E 14th St and Madison Ave	0	0	420	332	0	231	203	215
161	Des Moines	Delaware Ave and Guthrie Ave	0	0	0	0	356	139	221	216
282	Des Moines	W 19th St and Day St	0	0	0	0	279	196	459	218
62	Des Moines	US 69/E 14th St and Cleveland Ave	0	0	400	374	365	377	212	223
1332	Des Moines	35th St and University Ave	0	0	0	0	0	0	381	227
5058	Ames	Beach (Wallace) and Lincoln Way	0	0	342	0	459	284	178	229
10	Des Moines	US 69/SE 14th St and Indianola Ave	0	189	64	169	61	28	38	230
105	Des Moines	M.L. King Jr Pkwy and University Ave	0	0	0	424	222	164	351	241
61	Des Moines	US 69/E 14th St and Washington St	0	197	104	72	284	499	291	243
76	Des Moines	42nd St and University Ave	0	397	106	150	50	194	50	245
5035	Ames	Walnut and S. 3rd	0	0	0	0	415	297	225	247
251	Des Moines	6th St and Locust St	0	0	0	116	106	68	216	251
5059	Ames	Elwood Dr. and Lincoln Way	0	0	0	0	0	0	480	255
122	Des Moines	M.L. King Jr Pkwy and Woodland Ave	0	107	233	157	0	0	461	265
276	Des Moines	3rd St and I-235 EB Off-Ramp/S	0	192	445	0	37	62	229	276
129	Des Moines	M.L. King Jr Pkwy and Forest Ave	0	22	24	110	203	213	150	282
30	Des Moines	Fleur Dr and IA 5/Army Post Rd	0	0	0	0	0	0	345	283
291	Des Moines	IA 28/Merle Hay R and I-80 EB	0	0	0	0	0	0	334	293
5190	Ames	Grand and 20th St.	0	0	0	0	0	0	346	308
188	Des Moines	Southridge Mall E and IA 5/Army Post Rd	0	14	19	50	81	254	328	341
80	Des Moines	IA 28/63rd St and University Ave	0	184	136	96	0	391	363	346
165	Des Moines	E 25th St and US 6/Euclid Ave	0	0	0	497	154	89	313	348
210	Des Moines	7th St and Center St	0	0	0	0	0	0	343	358
186	Des Moines	SW 42nd St and IA 5/Army Post Rd (	0	0	0	0	0	0	399	361
283	Des Moines	31st St and Crocker St/WB I-235	0	0	0	0	0	0	625	365
55	Des Moines	US 69/E 14th St and Aurora Ave	0	88	46	53	94	122	266	366
81	Des Moines	IA 28/63rd St and US 6/Hickman Rd	0	0	0	0	142	260	590	371
38	Des Moines	42nd St and Grand Ave	0	0	0	278	42	32	784	376
124	Des Moines	W 19th St/Keo Way and Carpenter Ave	0	371	341	354	0	0	1475	384
5068	Ames	Clark (Walnut) and Lincoln Way	0	0	0	0	0	0	429	409
248	Des Moines	7th St and Locust St	0	425	0	0	0	0	315	411
162	Des Moines	Dixon Ave and Guthrie Ave	0	0	0	0	0	0	226	434
216	Des Moines	5th Ave and Crocker St	0	0	0	0	0	0	705	441
285	Des Moines	Polk Blvd and Center St	0	0	0	0	0	0	1954	463

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
108	Des Moines	E 6th St and Locust St	0	0	0	358	131	166	207	464
5148	Ames	Grand and 13th St.	0	0	0	0	0	0	436	473
233	Des Moines	7th St and Grand Ave	0	0	0	428	238	261	419	488
8	Des Moines	US 69/SE 14th St and McKinley Ave	0	0	0	0	229	138	244	498
14	Des Moines	SW 9th St and Watrous Ave	0	0	0	0	0	0	523	501
13	Des Moines	SW 9th St and McKinley Ave	0	0	0	264	82	52	101	504
67	Des Moines	IA 415/2nd Ave and Aurora Ave	0	244	182	132	0	0	1210	521
177	Des Moines	US 69/E 15th St and Grand Ave	50	107	170	385	0	0	891	526
148	Des Moines	Beaver Ave and Franklin Ave	0	0	0	0	0	0	824	531
86	Des Moines	6th Ave and Hickman Rd/Arlingto	0	0	0	0	0	0	562	536
267	Des Moines	3rd St and Walnut St	0	0	0	0	0	0	1301	541
5044	Ames	Franklin and Lincoln Way	0	0	0	0	0	0	428	555
57	Des Moines	US 69/E 14th St and US 6/Euclid Ave	28	33	53	42	268	340	413	556
141	Des Moines	IA 28/Merle Hay R and Aurora Ave	5	9	27	29	245	269	154	578
1340	Des Moines	34th St and University Ave	0	0	0	473	0	0	682	584
167	Des Moines	E 29th St and US 6/Euclid Ave	0	0	0	0	468	492	539	591
114	Des Moines	E 30th St and Dean Ave	0	194	154	113	272	247	242	614
32	Des Moines	Fleur Dr and McKinley Ave	220	226	0	0	0	0	775	636
83	Des Moines	Beaver Ave and Hickman Rd	0	0	0	0	161	0	603	639
154	Des Moines	7th St and Tuttle St	0	0	0	0	0	0	400	649
1164	Des Moines	SW 14th St and Leland Ave	0	0	0	0	0	0	489	658
101	Des Moines	9th St and University Ave	0	0	413	308	344	0	759	670
2013	Des Moines	E 4th St and Court Ave	0	0	0	0	0	0	615	672
5019	Ames	Elwood Dr. and Mortenson Rd.	0	0	0	0	0	341	331	710
171	Des Moines	E 33rd St and Easton Blvd	0	0	0	0	0	0	796	724
5040	Ames	South Dakota and Lincoln Way	0	8	16	122	0	0	1337	730
118	Des Moines	E 33rd St and IA 163/University A	0	0	0	0	0	0	1697	736
113	Des Moines	SE 30th St and Scott Ave	0	0	0	0	385	320	557	738
5210	Ames	Grand and Northwood	0	0	0	0	0	0	542	769
1802	Des Moines	38th St and US 6/Douglas Ave	0	0	0	0	461	0	778	772
5055	Ames	Lynn and Lincoln Way	0	0	0	0	0	0	670	774
1031	Des Moines	SW 14th St and Park Ave	0	0	0	0	0	0	668	786
5070	Ames	Kellogg and Lincoln Way	0	0	0	0	0	0	1295	790
157	Des Moines	IA 28/63rd St and Park Ave	0	0	0	0	0	0	1064	794
54	Des Moines	US 69/NE 14th St and NE 46th Ave/Broadwa	0	89	28	68	127	311	634	809
110	Des Moines	E 6th St and Grand Ave	0	125	123	88	236	0	1025	827
5031	Ames	Elwood Dr. and S. 4th St	0	0	0	0	0	0	2473	858
152	Des Moines	31st St and Kingman Blvd	0	0	0	0	0	0	684	860
79	Des Moines	Merle Hay Rd and University Ave	0	0	0	0	491	0	1021	863
5143	Ames	Northwestern and 13th St.	0	0	0	0	0	0	1051	872
297	Des Moines	2nd Ave and I-80 EB	0	0	237	330	0	0	2714	881
1214	Des Moines	SW 9th St and Payton Ave	0	0	0	0	0	0	976	882
163	Des Moines	Dixon Ave/McDonal and US 6/Euclid Ave	0	0	0	0	0	0	434	884

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
176	Des Moines	E 16th St and Grand Ave	0	0	0	0	0	0	1034	900
142	Des Moines	IA 28/Merle Hay R and Madison Ave	0	0	89	401	0	0	1068	901
236	Des Moines	8th St and Grand Ave	0	416	483	284	0	0	871	902
52	Des Moines	Indianola Ave and Park Ave	0	0	0	0	0	480	1014	907
71	Des Moines	2nd Ave and Hull Ave	0	0	0	0	0	0	657	924
292	Des Moines	IA 28/Merle Hay R and I-80 WB	0	0	365	0	0	0	816	929
5173	Ames	Grand and 16th St.	0	0	0	0	0	0	1278	969
130	Des Moines	M.L. King Jr Pkwy and Carpenter Ave	0	0	0	0	0	0	1495	971
241	Des Moines	SW 9th St and Mulberry St	0	117	149	61	0	424	1176	979
259	Des Moines	3rd St and Grand Ave	0	0	0	0	0	0	1158	981
190	Des Moines	Indianola Dr and Army Post Rd	0	0	0	492	186	93	716	999
5050	Ames	Hyland Ave. and Lincoln Way	0	0	0	0	0	0	1325	1008
1602	Des Moines	W 19th St and College Ave	0	0	0	0	0	0	807	1012
40	Des Moines	17th St/18th St and Ingersoll Ave	0	0	0	0	0	0	656	1014
123	Des Moines	W 19th St and Cottage Grove Ave/C	0	0	0	0	0	0	1196	1018
66	Des Moines	IA 415/2nd Ave and Broadway Ave	0	0	0	0	0	0	1123	1033
1	Des Moines	US 69/SE 14th St and Hartford Ave	0	0	242	0	0	0	1138	1048
280	Des Moines	9th St and Day St/I-235 WB	0	0	0	0	0	0	1081	1056
20	Des Moines	Fleur Dr and Watrous Ave	0	0	0	0	0	0	1033	1081
172	Des Moines	E 29th St and Easton Blvd	0	0	0	0	0	0	2698	1086
174	Des Moines	E 18th St and Grand Ave/Hubbell A	0	0	0	0	0	0	867	1089
6	Des Moines	US 69/SE 14th St and Diehl Ave	0	0	0	0	0	0	1935	1130
46	Des Moines	SE 6th St and Hartford Ave	0	0	0	0	0	0	3847	1134
107	Des Moines	E 6th St and Walnut St	0	268	284	153	51	78	393	1139
2014	Des Moines	E 4th St and Walnut St	0	0	0	0	0	0	1718	1181
262	Des Moines	2nd Ave and Walnut St	0	0	0	0	0	0	1233	1192
5056	Ames	Ash Ave. and Lincoln Way	0	0	0	0	0	0	753	1201
221	Des Moines	13th St and Locust St	0	0	0	437	0	0	1647	1252
75	Des Moines	31st St and University Ave	0	0	0	0	366	220	1041	1256
5154	Ames	Duff Ave. and 13th St.	0	0	0	0	0	472	705	1265
205	Des Moines	7th Ave and Park St	0	0	0	0	0	0	1536	1284
59	Des Moines	US 69/E 14th St and Grandview Ave	0	0	0	0	0	0	1350	1313
1235	Des Moines	SW 5th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	1234	1335
223	Des Moines	13th St and Walnut St	0	0	0	0	0	0	751	1395
5025	Ames	Elwood Dr. and S. 16th St	0	0	0	0	0	0	2445	1396
144	Des Moines	Lower Beaver Rd and Madison Ave	0	0	0	0	0	0	1452	1399
1059	Des Moines	South Union and McKinley Ave	0	0	0	0	0	0	2364	1400
1254	Des Moines	South Union and Kenyon Ave	0	0	0	0	0	0	1016	1426
206	Des Moines	12th St and Keo Way	0	0	0	0	0	0	820	1446
219	Des Moines	12th St and Grand Ave	0	0	0	0	0	0	1579	1482
5100	Ames	Grand and 9th St.	0	0	0	0	0	0	2069	1516
120	Des Moines	E 26th St and IA 163/University A	0	0	0	0	0	0	2060	1534
74	Des Moines	28th St and University Ave	0	0	0	0	0	0	1949	1536

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
5202	Ames	Grand and 30th St.	0	0	0	0	0	0	1129	1550
252	Des Moines	6th St and Mulberry St	0	0	0	0	0	0	2042	1613
1701	Des Moines	W 21st St and Forest Ave	0	0	0	0	406	0	1486	1618
185	Des Moines	IA 28/63rd St and SW McKinley Ave	0	0	0	0	0	0	1957	1645
132	Des Moines	6th Ave and Forest Ave	0	0	0	0	0	0	1616	1664
5072	Ames	Duff Ave. and Lincoln Way	0	0	0	0	0	0	1802	1707
2012	Des Moines	E 5th St and Grand Ave	0	0	0	0	0	0	1772	1742
5038	Ames	Duff Ave. and S. 2nd	0	0	0	0	0	0	1530	1762
258	Des Moines	4th St and Grand Ave	0	0	0	491	337	0	1323	1784
127	Des Moines	M.L. King Jr Pkwy and Urbandale Ave	0	0	0	0	0	0	1665	1790
260	Des Moines	2nd Ave and Grand Ave	0	41	41	25	477	0	1670	1845
135	Des Moines	6th Ave and Madison Ave	0	0	0	0	0	0	1710	1903
5064	Ames	Oak and Lincoln Way	0	0	0	0	0	0	1516	1914
31	Des Moines	Fleur Dr and Highview Dr	0	0	0	0	0	0	2685	1993
183	Des Moines	SW 14th St and McKinley Ave	0	0	0	0	0	0	1747	2012
1339	Des Moines	41st St and University Ave	0	0	0	0	0	0	1083	2016
42	Des Moines	28th St and Ingersoll AVe	0	291	364	406	0	0	889	2026
246	Des Moines	SW 8th St and Mulberry St	0	0	0	0	0	0	1879	2035
1736	Des Moines	30th St and Leado Ave	0	0	0	0	0	0	2157	2046
5029	Ames	Hayward and Mortenson Rd.	0	0	0	0	0	0	2231	2106
12	Des Moines	US 69/SE 14th St and Bell Ave	0	0	0	0	0	0	1547	2113
33	Des Moines	19th St and Grand Ave	0	0	0	0	0	0	667	2137
203	Des Moines	3rd St and Watson Powell/Keo W	0	0	518	0	0	0	1938	2220
84	Des Moines	30th St and Hickman Rd	0	0	0	0	0	0	3344	2228
245	Des Moines	7th St and Mulberry St	0	399	385	426	0	0	1946	2241
34	Des Moines	28th St and Grand Ave	0	0	0	0	0	0	1309	2252
23	Des Moines	Fleur Dr and Valley Dr	0	0	0	0	436	0	875	2263
200	Des Moines	8th St and High St	0	0	0	0	0	0	1789	2295
36	Des Moines	35th St and Grand Ave	0	0	0	0	0	0	2653	2295
50	Des Moines	SW 7th St and Indianola Ave	0	0	0	0	0	0	2138	2316
5043	Ames	Marshall and Lincoln Way	0	0	0	0	0	0	2726	2376
5071	Ames	Sherman and Lincoln Way	0	0	0	0	0	0	5716	2417
197	Des Moines	9th St and Pleasant St	0	0	0	0	0	0	2324	2427
1348	Des Moines	34th St and Forest Ave	0	0	0	0	0	0	2893	2456
5065	Ames	Elm and Lincoln Way	0	0	0	0	0	0	3594	2466
5140	Ames	Hyland Ave. and Ontario	0	0	0	0	0	0	4135	2526
2016	Des Moines	E 3rd St and Walnut St	0	0	0	0	0	0	3275	2527
173	Des Moines	Hubbell Ave and Easton Blvd	0	0	0	0	0	0	2857	2574
5142	Ames	Ridgewood and 13th St.	0	366	213	0	0	0	2351	2601
131	Des Moines	6th Ave and Laurel Ave	0	0	0	0	0	0	3885	2608
5041	Ames	Beedle Dr. and Lincoln Way	0	0	0	0	0	0	1888	2638
1720	Des Moines	30th St and Clark St	0	0	0	0	0	0	2446	2667
19	Des Moines	Fleur Dr and Stanton Ave	0	0	487	0	0	0	2369	2674

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
222	Des Moines	12th St and Locust St	0	0	0	0	0	0	1795	2675
95	Des Moines	59th St and Douglas Ave	0	0	0	0	0	0	2677	2679
2023	Des Moines	11th St and Locust St	0	0	0	0	0	0	3321	2722
109	Des Moines	E 9th St/Finkbine and Grand Ave	0	0	0	0	0	0	1830	2763
1771	Des Moines	38th St and Adams Ave	0	0	0	0	0	0	2930	2776
16	Des Moines	SW 9th St and Bell Ave (south)	0	0	0	0	0	0	2395	2830
111	Des Moines	Pennsylvania Ave and Grand Ave	0	0	0	0	0	0	2036	2837
72	Des Moines	IA 415/2nd Ave and New York Ave	0	0	0	0	0	0	1791	2843
48	Des Moines	Indianola Ave and Hartford Ave	0	0	0	0	0	0	2477	2860
5057	Ames	Knoll Rd. and Lincoln Way	0	0	0	0	0	0	1532	2867
1131	Des Moines	South Union and Watrous Ave	0	0	0	0	0	0	4261	2870
1118	Des Moines	SW 12th St and Watrous Ave	0	0	0	0	0	0	1891	2875
5046	Ames	Willmoth and Lincoln Way	0	0	0	0	0	0	1812	2882
91	Des Moines	Lower Beaver Rd/E and US 6/Douglas Ave	0	0	0	0	0	0	1893	3013
159	Des Moines	E 29th St and Hubbell Ave	0	0	0	0	0	0	5490	3073
133	Des Moines	6th Ave and College Ave	0	0	0	0	0	0	3228	3081
212	Des Moines	6th Ave and Park St	0	0	0	0	0	0	2131	3096
151	Des Moines	25th St and Forest Ave	0	0	0	0	0	0	1851	3138
1184	Des Moines	SW 14th St and Payton Ave	0	0	0	0	0	0	0	3141
49	Des Moines	SE 1st St and Indianola Ave	0	0	0	0	0	0	4694	3153
104	Des Moines	24th St and University Ave	0	0	0	0	0	0	2604	3202
237	Des Moines	9th St and Grand Ave	0	163	274	201	0	0	1589	3255
1643	Des Moines	M.L. King Jr Pkwy and Franklin Ave	0	0	0	0	0	0	4517	3406
1290	Des Moines	34th St and Hickman Rd	0	0	0	0	0	0	2179	3419
198	Des Moines	9th St and High St	0	0	0	0	0	0	3625	3457
168	Des Moines	E 33rd St and US 6/Euclid Ave	0	0	0	351	295	425	3735	3463
5084	Ames	Duff Ave. and 6th St.	0	0	0	0	0	0	3828	3484
39	Des Moines	56th St and Grand Ave	0	0	0	0	0	0	3473	3511
234	Des Moines	10th St and Grand Ave	0	298	212	197	0	0	1976	3544
1704	Des Moines	24th St and Forest Ave	0	0	0	0	0	0	2977	3551
5048	Ames	State and Lincoln Way	0	0	0	0	0	0	609	3556
47	Des Moines	SE 5th St/SE 6th and Indianola Ave	0	0	0	233	0	0	1864	3581
265	Des Moines	1st St/Riverside and Court Ave	0	0	0	0	0	0	2165	3596
196	Des Moines	10th St and High St	0	0	0	0	0	0	3544	3617
5036	Ames	Duff Ave. and S. 3rd	0	0	0	0	0	0	5937	3627
1358	Des Moines	41st St and Forest Ave	0	0	0	0	0	0	2345	3685
1746	Des Moines	38th St and Urbandale Ave	0	0	0	0	0	0	1669	3908
224	Des Moines	15th St and Locust St	0	0	0	0	0	0	3467	3912
1302	Des Moines	38th St and Franklin Ave	0	0	0	0	0	0	0	3915
137	Des Moines	E 9th St and Cleveland Ave	0	0	0	0	0	0	2562	3925
5155	Ames	Haber Rd. and 13th St.	0	0	0	0	0	0	2885	3939
1249	Des Moines	South Union and Wall Ave	0	0	0	0	0	0	2513	4019
138	Des Moines	Pennsylvania Ave and Fremont St	0	0	0	0	0	0	5326	4074

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
201	Des Moines	6th Ave and High St	0	0	0	0	0	0	3260	4156
128	Des Moines	M.L. King Jr Pkwy and Clark St	0	427	376	0	0	0	4339	4212
180	Des Moines	E 1st St and Grand Ave	0	0	0	0	0	0	4520	4229
239	Des Moines	10th St and Locust St	0	0	441	0	0	0	5547	4341
73	Des Moines	25th St and University Ave	0	0	0	0	0	0	2080	4346
5062	Ames	Hazel and Lincoln Way	0	0	0	0	0	0	3492	4368
1241	Des Moines	SW 9th St and Leland Ave	0	0	0	0	0	0	3431	4385
263	Des Moines	2nd Ave and Court Ave	0	0	0	0	0	0	4956	4481
5033	Ames	Duff Ave. and S. 5th	0	0	0	237	69	118	2666	4521
211	Des Moines	6th Ave and Center St	0	0	0	0	0	0	2410	4526
2040	Des Moines	E 7th St and Walnut St	0	0	0	0	0	0	1931	4564
231	Des Moines	13th St and Grand Ave	0	0	0	0	0	0	5460	4607
2035	Des Moines	14th St and Grand Ave	0	0	0	0	0	0	5431	4634
289	Des Moines	IA 28/63rd St and I-235 WB	0	0	0	0	0	0	4576	4639
1027	Des Moines	South Union and Park Ave	0	0	0	0	0	0	3392	4644
1333	Des Moines	36th St and University Ave	0	0	0	0	0	0	7557	4692
226	Des Moines	Fleur Dr and Grand Ave	0	0	0	0	0	0	5236	4724
155	Des Moines	42nd St and Park Ave	0	0	0	0	0	0	6375	4725
5052	Ames	Hayward and Lincoln Way	0	0	0	0	0	0	4164	4733
1652	Des Moines	30th St and US 6/Douglas Ave	0	0	0	0	0	0	5221	4738
227	Des Moines	Fleur Dr and Locust St	0	0	0	0	0	0	5110	4776
1322	Des Moines	41st St and Beaver Ave	0	0	0	0	0	0	4985	4881
5042	Ames	Dotson and Lincoln Way	0	0	0	0	0	0	5052	4922
284	Des Moines	42nd St and Crocker St	0	0	0	0	0	0	2047	4943
5075	Ames	Duff Ave. and Main St.	0	0	0	0	0	0	7192	4953
264	Des Moines	3rd St and Court Ave	0	0	0	0	0	0	3726	4962
5093	Ames	Grand and 8th St.	0	0	0	0	0	0	5726	5036
2004	Des Moines	E 1st St and Locust St	0	0	0	0	0	0	4588	5115
181	Des Moines	E 4th St and Grand Ave	0	0	0	0	0	0	3825	5134
5015	Ames	Duff Ave. and Airport Rd.	0	0	0	0	0	0	5167	5141
256	Des Moines	5th St and Walnut St	0	0	0	0	0	0	7675	5149
1622	Des Moines	26th St and Hickman Rd	0	0	0	0	0	0	9511	5180
115	Des Moines	E 30th St and Walnut St	0	0	0	0	0	0	2419	5248
170	Des Moines	NE 46th St and US 6/Hubbell Ave	0	0	0	0	0	0	5195	5256
166	Des Moines	E 26th St and US 6/Euclid Ave	0	0	0	0	0	0	3865	5289
2021	Des Moines	11th St and Grand Ave	0	0	0	0	0	0	4949	5453
1070	Des Moines	SW 9th St and Hackley Ave	0	0	0	0	0	0	4174	5585
5049	Ames	Campus Ave. and Lincoln Way	0	0	0	0	0	0	4831	5639
207	Des Moines	9th St and Keo Way	0	0	0	0	0	0	7361	5701
1159	Des Moines	SW 9th St and Thornton Ave	0	0	0	0	0	0	5435	5902
1663	Des Moines	M.L. King Jr Pkwy and Prospect Rd	0	0	0	0	0	0	6478	6212
28	Des Moines	SW 14th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	5362	6270
51	Des Moines	SE 1st St and Jackson Ave	0	0	0	0	0	0	5982	6305

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
193	Des Moines	IA 28/63rd St/1st and IA 5/Army Post Rd	0	0	0	0	0	0	8654	6432
179	Des Moines	E 4th St and Locust St	0	0	0	0	372	0	3629	6451
199	Des Moines	8th St and Pleasant St	0	0	0	0	0	0	5045	6485
17	Des Moines	SW 8th St/SW 9th and MTA Lane	0	0	0	0	0	0	7216	6545
5030	Ames	Welch Rd. and Mortenson Rd.	0	0	0	0	0	0	5339	6549
112	Des Moines	E 12th St and Grand Ave	0	0	0	0	0	0	5924	6621
1229	Des Moines	SW 3rd St and Iowa 5/Army Post Ro	0	0	0	0	0	0	5704	6633
1349	Des Moines	Beaver Ave and Forest Ave	0	0	0	0	0	0	6237	6703
2031	Des Moines	14th St and Locust St	0	0	0	0	0	0	6963	6771
1170	Des Moines	SW 12th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	7273	6775
5191	Ames	Duff Ave. and 20th St.	0	0	0	0	0	0	9224	6781
134	Des Moines	6th Ave and Holcomb Ave	0	0	157	435	0	0	5918	6836
5195	Ames	Duff Ave. and 24th St.	0	0	0	0	0	0	9168	6852
1346	Des Moines	32nd St and Forest Ave	0	0	0	0	0	0	7825	6865
1256	Des Moines	South Union and Porter Ave	0	0	0	0	0	0	6946	6929
5027	Ames	South Dakota and Mortenson Rd.	0	0	0	0	0	0	0	7058
5054	Ames	Stanton and Lincoln Way	0	0	0	0	0	0	5803	7076
1744	Des Moines	36th St and Urbandale Ave	0	0	0	0	0	0	0	7105
249	Des Moines	6th St and Walnut St	0	0	0	0	0	0	8760	7274
1201	Des Moines	SW 9th St and Frazier Ave	0	0	0	0	0	0	8741	7330
1714	Des Moines	23rd St and University Ave	0	0	0	0	0	0	6031	7339
2006	Des Moines	E 2nd St and Grand Ave	0	0	0	0	0	0	7396	7359
5179	Ames	Duff Ave. and 16th St.	0	0	0	0	0	0	5786	7486
5002	Ames	Duff Ave. and Garden Rd	0	0	0	0	0	0	7434	7534
77	Des Moines	Polk Blvd and University Ave	0	0	0	0	0	0	7517	7559
5018	Ames	Beach (Wallace) and Mortenson Rd.	0	0	0	0	0	0	0	7592
182	Des Moines	SE 5th St and Porter Ave	0	0	0	0	0	0	7297	7736
5034	Ames	Walnut and S. 4th	0	0	0	0	0	0	0	7771
1102	Des Moines	SW 9th St and Lewis Ave	0	0	0	0	0	0	5038	7810
1733	Des Moines	30th St and Sheridan Ave	0	0	0	0	0	0	0	7866
230	Des Moines	15th St and Grand Ave	0	0	0	0	0	0	7314	7922
78	Des Moines	56th St and University Ave	0	0	0	0	0	0	8420	7996
1607	Des Moines	M.L. King Jr Pkwy and Lincoln Ave	0	0	0	0	0	0	4522	8151
153	Des Moines	28th St and Cottage Grove Ave	0	0	0	0	0	0	5011	8302
1360	Des Moines	42nd St and Forest Ave	0	0	0	0	0	0	7186	8496
242	Des Moines	SW 9th St and Walnut St	0	0	0	0	0	0	6473	8543
1009	Des Moines	SW 12th St and Park Ave	0	0	0	0	0	0	8790	8567
1667	Des Moines	M.L. King Jr Pkwy and Welbeck Rd	0	0	0	0	0	0	0	8609
1658	Des Moines	24th St and Hickman Rd	0	0	0	0	0	0	9352	8666
244	Des Moines	8th St and Walnut St	0	0	0	0	0	0	9697	8793
5152	Ames	Kellogg and 13th St.	0	0	0	0	0	0	8839	8824
5067	Ames	Gilchrist and Lincoln Way	0	0	0	0	0	0	9929	8836
266	Des Moines	4th St and Court Ave	0	0	7662	0	0	0	9651	8901

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1735	Des Moines	30th St and Payne Rd	0	0	0	0	0	0	8968	8932
1161	Des Moines	SW 9th St and Rose Ave	0	0	0	0	0	0	9760	9016
2018	Des Moines	4th St and Locust St	0	0	0	0	0	0	9687	9020
1647	Des Moines	27th St and US 6/Douglas Ave	0	0	0	0	0	0	0	9069
2009	Des Moines	E 5th St and Locust St	0	0	0	0	0	0	0	9090
24	Des Moines	Fleur Dr and Grays Lake	0	0	0	0	0	0	9308	9106
217	Des Moines	5th St and Center St	0	0	0	0	0	0	9062	9123
1069	Des Moines	SW 9th St and Titus Ave	0	0	0	0	0	0	8590	9159
184	Des Moines	24th St and Park Ave	0	0	0	0	0	0	0	9306
5107	Ames	Grand and 10th St.	0	0	0	0	0	0	9929	9395
1712	Des Moines	W 21st St and University Ave	0	0	0	0	0	0	9011	9408
5077	Ames	Duff Ave. and 5th St.	0	0	0	0	0	0	5372	9470
37	Des Moines	37th St and Grand Ave	0	0	0	0	0	0	8468	9538
1172	Des Moines	SW 13th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	9415	9574
1186	Des Moines	SW 7th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	9960	9736
5121	Ames	Grand and 12th St.	0	0	0	0	0	0	10310	9782
1604	Des Moines	M.L. King Jr Pkwy and Washington Ave/W 19	0	0	0	0	0	0	10389	9784
1341	Des Moines	32nd St and University Ave	0	0	0	0	0	0	0	9809
5069	Ames	Washington and Lincoln Way	0	0	0	0	0	0	10014	9960
5153	Ames	Douglas and 13th St.	0	0	0	0	0	0	0	9974
213	Des Moines	6th Ave and Watson Powell/Keo W	0	0	0	0	0	0	0	9983
269	Des Moines	5th St and Locust St	0	0	0	0	0	0	10097	10026
1104	Des Moines	SW 9th St and Emma Ave (north)	0	0	0	0	0	0	7610	10069
218	Des Moines	5th Ave and Park St	0	0	0	0	0	0	0	10126
1717	Des Moines	29th St and University Ave	0	0	0	0	0	0	0	10153
1666	Des Moines	M.L. King Jr Pkwy and Boston Ave	0	0	0	0	0	0	7988	10158
1640	Des Moines	M.L. King Jr. Pkw and Post St	0	0	0	0	0	0	8836	10159
5045	Ames	Colorado and Lincoln Way	0	0	0	0	0	0	9784	10172
225	Des Moines	17th St and Locust St	0	0	0	0	0	0	8128	10196
2020	Des Moines	2nd Ave and Watson Powell/Keo W	0	0	0	0	0	0	9708	10199
1713	Des Moines	22nd St and University Ave	0	0	0	0	0	0	8286	10229
254	Des Moines	SW 5th St and Cherry St	0	0	0	0	0	0	0	10233
1099	Des Moines	SW 9th St and Trowbridge St/Elder	0	0	0	0	0	0	10342	10270
250	Des Moines	7th St and Walnut St	0	0	0	0	0	0	6866	10328
220	Des Moines	12th St and High St	0	0	0	0	0	0	0	10379
1171	Des Moines	SW 12th Pl and Iowa 5/Army Post Ro	0	0	0	0	0	0	0	10399
1299	Des Moines	40th Pl and Hickman Rd	0	0	0	0	0	0	0	10449
1242	Des Moines	SW 9th St and Lally St	0	0	0	0	0	0	0	10451
5165	Ames	Grand and 15th St.	0	0	0	0	0	0	9630	10460
2	Des Moines	US 69/SE 14th St and Maury St	66	0	0	0	0	0	0	0
9	Des Moines	US 69/SE 14th St and WAtrous Ave	189	0	0	0	0	0	0	0
21	Des Moines	Fleur Dr and Park Ave	132	0	0	0	0	0	0	0
26	Des Moines	SW 9th St and Porter Ave	135	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
43	Des Moines	31st St and Ingersoll Ave	147	0	0	0	0	0	0	0
44	Des Moines	35th St and Ingersoll Ave	366	0	0	0	0	0	0	0
45	Des Moines	42nd St and Ingersoll Ave	300	0	0	0	0	0	0	0
60	Des Moines	US 69/E 14th St and Guthrie Ave	20	0	0	0	0	0	0	0
63	Des Moines	US 69/E 14th St and IA 163/University A	373	0	0	0	0	0	0	0
68	Des Moines	IA 415/2nd Ave and Madison Ave	145	0	0	0	0	0	0	0
85	Des Moines	M.L. King Jr Pkwy and Hickman Rd	173	0	0	0	0	0	0	0
87	Des Moines	Cornell Ave and US 6/Euclid Ave	138	0	0	0	0	0	0	0
88	Des Moines	6th Ave and US 6/Euclid Ave	96	0	0	0	0	0	0	0
90	Des Moines	M.L. King Jr. Pkw and US 6/Douglas Ave/Eu	8	5	40	22	0	0	0	0
93	Des Moines	50th St and US 6/Douglas Ave	56	0	0	0	0	0	0	0
98	Des Moines	E 9th St and University Ave	116	0	0	0	0	0	0	0
99	Des Moines	Pennsylvania Ave and University Ave	58	0	0	0	0	0	0	0
102	Des Moines	13th St and University Ave	222	0	0	0	0	0	0	0
103	Des Moines	W 19th St and University Ave	38	0	0	0	0	0	0	0
106	Des Moines	E 6th St and Court Ave	148	0	0	0	0	0	0	0
116	Des Moines	E 30th St and Grand Ave	123	0	0	0	0	0	0	0
136	Des Moines	E 9th St and Hull Ave	0	0	0	0	0	0	0	0
140	Des Moines	IA 28/Merle Hay R and Meredith Dr	358	0	0	0	0	0	0	0
143	Des Moines	Beaver Rd and Madison Ave	76	0	0	0	0	0	0	0
147	Des Moines	44th St and Franklin Ave	0	0	0	0	0	0	0	0
149	Des Moines	30th St and Forest Ave	334	0	0	0	0	0	0	0
156	Des Moines	56th St and Park Ave	0	0	0	0	0	0	0	0
169	Des Moines	E 38th St and US 6/Hubbell Ave	238	0	0	0	0	0	0	0
178	Des Moines	US 69/E 14th St and Grand Ave	37	0	0	0	0	0	0	0
192	Des Moines	US 69/E 14th St and Walnut Ave	230	0	0	0	0	0	0	0
204	Des Moines	3rd St and Park St	0	0	0	0	0	0	0	0
208	Des Moines	Keo Way and Park St	0	0	0	0	0	0	0	0
209	Des Moines	9th St and Center St	0	0	0	0	0	0	0	0
214	Des Moines	4th St and Watson Powell/Keo W	0	0	0	0	0	0	0	0
215	Des Moines	5th Ave and Watson Powell/Keo W	0	0	0	0	0	0	0	0
228	Des Moines	17th St and Grand Ave	105	0	0	0	0	0	0	0
235	Des Moines	10th St and Walnut St	0	0	0	0	0	0	0	0
238	Des Moines	9th St and Locust Ave	131	0	0	0	0	0	0	0
240	Des Moines	10th St and Mulberry St	0	0	0	0	0	0	0	0
243	Des Moines	8th St and Locust St	31	0	0	0	0	0	0	0
253	Des Moines	6th Ave and Cherry St	0	0	0	0	0	0	0	0
255	Des Moines	5th St and Mulberry St	0	0	0	0	0	0	0	0
270	Des Moines	4th St and Walnut St	0	0	0	0	0	0	0	0
274	Des Moines	E 6th St and I-235 WB	129	0	0	0	0	0	0	0
277	Des Moines	5th St and I-235 EB On-Ramp/Sc	57	0	0	0	0	0	0	0
279	Des Moines	6th Ave and Day St/I-235 WB	225	0	0	0	0	0	0	0
290	Des Moines	IA 28/Merle Hay R and Sutton Pl	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1001	Des Moines	SW 13th Pl and Park Ave	0	0	0	0	0	0	0	0
1002	Des Moines	SW 13th Pl and Caulder Ave	0	0	0	0	0	0	0	0
1003	Des Moines	SW 13th St and Park Ave	0	0	0	0	0	0	0	0
1004	Des Moines	SW 13th St and Caulder Ave	0	0	0	0	0	0	0	0
1005	Des Moines	SW 13th St and Thornton Ave	0	0	0	0	0	0	0	0
1006	Des Moines	SW 12th Pl and Thornton Ave	0	0	0	0	0	0	0	0
1007	Des Moines	SW 12th Pl and Caulder Ave	0	0	0	0	0	0	0	0
1008	Des Moines	SW 12th Pl and Park Ave	0	0	0	0	0	0	0	0
1010	Des Moines	SW 12th St and Caulder Ave	0	0	0	0	0	0	0	0
1011	Des Moines	SW 12th St and Hyde Dr	0	0	0	0	0	0	0	0
1012	Des Moines	SW 12th St and Thornton Ave	0	0	0	0	0	0	0	0
1013	Des Moines	Glover Ave and Thornton Ave	0	0	0	0	0	0	0	0
1014	Des Moines	Glover Ave and Jarvis St	0	0	0	0	0	0	0	0
1015	Des Moines	Glover Ave and Caulder Ave	0	0	0	0	0	0	0	0
1016	Des Moines	Hyde Dr and Caulder Ave	0	0	0	0	0	0	0	0
1017	Des Moines	Glover Ave and Hughes Ave	0	0	0	0	0	0	0	0
1018	Des Moines	Glover Ave and Park Ave	0	0	0	0	0	0	0	0
1019	Des Moines	Henry Ave and Park Ave	0	0	0	0	0	0	0	0
1020	Des Moines	Henry Ave and Caulder Ave	0	0	0	0	0	0	0	0
1021	Des Moines	SW 9th St and Jarvis St	0	0	0	0	0	0	0	0
1022	Des Moines	Keyes Dr and Jarvis St	0	0	0	0	0	0	0	0
1023	Des Moines	Keyes Dr and Thornton Ave	0	0	0	0	0	0	0	0
1024	Des Moines	Glover Ave and Wolcott Ave	0	0	0	0	0	0	0	0
1025	Des Moines	Glover Ave and Rose Ave	0	0	0	0	0	0	0	0
1028	Des Moines	SW 2nd Ave and Park Ave	0	0	0	0	0	0	0	0
1029	Des Moines	SW 14th St and Thornton Ave	0	0	0	0	0	0	0	0
1030	Des Moines	SW 14th St and Caulder Ave	0	0	0	0	0	0	0	0
1033	Des Moines	SW 10th St and Lewis Ave	0	0	0	0	0	0	0	0
1034	Des Moines	SW 10th St and Emma Ave	0	0	0	0	0	0	0	0
1035	Des Moines	SW 8th St and Emma Ave	0	0	0	0	0	0	0	0
1036	Des Moines	SW 6th St and Herold Ave	0	0	0	0	0	0	0	0
1037	Des Moines	SW 6th St and Emma Ave	0	0	0	0	0	0	0	0
1038	Des Moines	SW 5th St and Herold Ave	0	0	0	0	0	0	0	0
1039	Des Moines	SW 5th St and Emma Ave	0	0	0	0	0	0	0	0
1040	Des Moines	SW 5th St and Maxwelton Dr	0	0	0	0	0	0	0	0
1041	Des Moines	SW 3rd St and Maxwelton Dr	0	0	0	0	0	0	0	0
1042	Des Moines	SW 3rd St and Herold Ave	0	0	0	0	0	0	0	0
1043	Des Moines	SW 2nd Ave and Herold Ave	0	0	0	0	0	0	0	0
1044	Des Moines	SW 2nd Ave and Emma Ave	0	0	0	0	0	0	0	0
1045	Des Moines	SW 2nd AVe and Maxwelton Dr	0	0	0	0	0	0	0	0
1046	Des Moines	SW 2nd Ave and Philip St	0	0	0	0	0	0	0	0
1047	Des Moines	SW 5th St and Trowbridge St	0	0	0	0	0	0	0	0
1048	Des Moines	SW 5th St and Philip St	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1049	Des Moines	SW 7th St and Philip St	0	0	0	0	0	0	0	0
1050	Des Moines	SW 7th St and Trowbridge St	0	0	0	0	0	0	0	0
1051	Des Moines	SW 7th St and Leach Ave	0	0	0	0	0	0	0	0
1052	Des Moines	SW 7th St and Marion St	0	0	0	0	0	0	0	0
1053	Des Moines	SW 5th St and Marion St	0	0	0	0	0	0	0	0
1054	Des Moines	SW 5th St and Leach Ave	0	0	0	0	0	0	0	0
1055	Des Moines	South Union and Leach Ave	0	0	0	0	0	0	0	0
1056	Des Moines	South Union and Hackley Ave	0	0	0	0	0	0	0	0
1057	Des Moines	South Union and Titus Ave	0	0	0	0	0	0	0	0
1060	Des Moines	SW 2nd Ave and McKinley Ave	0	0	0	0	0	0	0	0
1062	Des Moines	SW 5th St and McKinley Ave	0	0	0	0	0	0	0	0
1064	Des Moines	SW 6th St and McKinley Ave	0	0	0	0	0	0	0	0
1065	Des Moines	SW 8th St and McKinley Ave	0	0	0	0	0	0	0	0
1066	Des Moines	SW 10th St and McKinley Ave	0	0	0	0	0	0	0	0
1067	Des Moines	SW 10th St and Evans St	0	0	0	0	0	0	0	0
1068	Des Moines	SW 10th St and Titus Ave	0	0	0	0	0	0	0	0
1071	Des Moines	SW 10th St and Hackley Ave	0	0	0	0	0	0	0	0
1072	Des Moines	SW 12th St and Hackley Ave	0	0	0	0	0	0	0	0
1073	Des Moines	SW 12th St and Titus Ave	0	0	0	0	0	0	0	0
1074	Des Moines	SW 12th St and Evans St	0	0	0	0	0	0	0	0
1075	Des Moines	SW 12th St and McKinley Ave	0	0	0	0	0	0	0	0
1076	Des Moines	SW 13th St and McKinley Ave	0	0	0	0	0	0	0	0
1077	Des Moines	SW 13th St and Evans St	0	0	0	0	0	0	0	0
1078	Des Moines	SW 13th St and Titus Ave	0	0	0	0	0	0	0	0
1079	Des Moines	SW 13th St and Hackley Ave	0	0	0	0	0	0	0	0
1080	Des Moines	SW 14th St and Hackley Ave	0	0	0	0	0	0	0	0
1081	Des Moines	SW 14th St and Spring St	0	0	0	0	0	0	0	0
1082	Des Moines	SW 13th Pl and Elder Lane	0	0	0	0	0	0	0	0
1083	Des Moines	SW 13th Pl and Lewis Ave	0	0	0	0	0	0	0	0
1084	Des Moines	SW 13th St and Carrie Ave	0	0	0	0	0	0	0	0
1085	Des Moines	SW 14th St and Frazier Ave	0	0	0	0	0	0	0	0
1086	Des Moines	SW 10th St and Elder Lane	0	0	0	0	0	0	0	0
1087	Des Moines	SW 12th St and Elder Lane	0	0	0	0	0	0	0	0
1088	Des Moines	SW 14th St and Linden Lane	0	0	0	0	0	0	0	0
1089	Des Moines	SW 14th St and Lewis Ave	0	0	0	0	0	0	0	0
1090	Des Moines	SW 14th St and Elder Lane	0	0	0	0	0	0	0	0
1091	Des Moines	SW 14th St and Herold Ave	0	0	0	0	0	0	0	0
1092	Des Moines	SW 14th St and Carrier Ave	0	0	0	0	0	0	0	0
1093	Des Moines	SW 14th St and Emma Ave	0	0	0	0	0	0	0	0
1094	Des Moines	SW 12th St and Carrie Ave	0	0	0	0	0	0	0	0
1095	Des Moines	SW 9th St and Marion St	0	0	0	0	0	0	0	0
1096	Des Moines	SW 13th Pl and Carrie Ave	0	0	0	0	0	0	0	0
1097	Des Moines	Glover Ave and Marion St	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1100	Des Moines	SW 9th St and Leach Ave	0	0	0	0	0	0	0	0
1103	Des Moines	SW 9th St and Maxwelton Dr	0	0	0	0	0	0	0	0
1105	Des Moines	SW 9th St and Emma Ave (south)	0	0	0	0	0	0	0	0
1106	Des Moines	SW 9th St and Herold Ave	0	0	0	0	0	0	0	0
1107	Des Moines	SW 12th St and Maish Ave	0	0	0	0	0	0	0	0
1108	Des Moines	SW 12th St and Rose Ave	0	0	0	0	0	0	0	0
1109	Des Moines	SW 12th St and Birch Lane	0	0	0	0	0	0	0	0
1110	Des Moines	Glover Ave and Watrous Ave	0	0	0	0	0	0	0	0
1111	Des Moines	SW 14th St and Birch Ave	0	0	0	0	0	0	0	0
1112	Des Moines	SW 4th St and Watrous Ave	0	0	0	0	0	0	0	0
1113	Des Moines	SW 5th St and Watrous Ave	0	0	0	0	0	0	0	0
1114	Des Moines	SW 7th St and Watrous Ave	0	0	0	0	0	0	0	0
1116	Des Moines	SW 7th St and Maish Ave	0	0	0	0	0	0	0	0
1117	Des Moines	SW 13th St and Watrous Ave	0	0	0	0	0	0	0	0
1120	Des Moines	SW 14th St and Watrous Ave	0	0	0	0	0	0	0	0
1121	Des Moines	SW 14th St and Rose Ave	0	0	0	0	0	0	0	0
1122	Des Moines	SW 13th St and Birch Lane	0	0	0	0	0	0	0	0
1123	Des Moines	SW 13th St and Rose Ave	0	0	0	0	0	0	0	0
1124	Des Moines	SW 2nd Ave and Watrous Ave	0	0	0	0	0	0	0	0
1125	Des Moines	SW 3rd St and Watrous Ave	0	0	0	0	0	0	0	0
1126	Des Moines	South Union and Rose Ave	0	0	0	0	0	0	0	0
1127	Des Moines	SW 3rd St and Rose Ave	0	0	0	0	0	0	0	0
1128	Des Moines	SW 2nd Ave and Rose Ave	0	0	0	0	0	0	0	0
1129	Des Moines	SW 8th St and Rose Ave	0	0	0	0	0	0	0	0
1130	Des Moines	SW 6th St and Rose Ave	0	0	0	0	0	0	0	0
1132	Des Moines	SW 4th St and Rose Ave	0	0	0	0	0	0	0	0
1134	Des Moines	SW 5th St and Park Ave	0	0	0	0	0	0	0	0
1135	Des Moines	SW 6th St and Park Ave	0	0	0	0	0	0	0	0
1136	Des Moines	SW 7th St and Park Ave	0	0	0	0	0	0	0	0
1138	Des Moines	SW 8th St and Park Ave	0	0	0	0	0	0	0	0
1139	Des Moines	SW 9th St and Caulder Ave	0	0	0	0	0	0	0	0
1141	Des Moines	SW 8th St and Caulder Ave	0	0	0	0	0	0	0	0
1142	Des Moines	SW 7th St and Caulder Ave	0	0	0	0	0	0	0	0
1143	Des Moines	SW 7th St and Hughes Ave	0	0	0	0	0	0	0	0
1144	Des Moines	SW 5th St and Hughes Ave	0	0	0	0	0	0	0	0
1145	Des Moines	SW 2nd Ave and Hughes Ave	0	0	0	0	0	0	0	0
1146	Des Moines	SW 2nd Ave and Caulder Ave	0	0	0	0	0	0	0	0
1147	Des Moines	SW 2nd Ave and Miller Ave	0	0	0	0	0	0	0	0
1148	Des Moines	SW 2nd Ave and Thornton Ave	0	0	0	0	0	0	0	0
1149	Des Moines	South Union and Thornton Ave	0	0	0	0	0	0	0	0
1150	Des Moines	SW 3rd St and Thornton Ave	0	0	0	0	0	0	0	0
1151	Des Moines	SW 4th St and Thornton Ave	0	0	0	0	0	0	0	0
1152	Des Moines	SW 5th St and Thornton Ave	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1153	Des Moines	SW 5th St and Miller Ave	0	0	0	0	0	0	0	0
1154	Des Moines	SW 7th St and Miller Ave	0	0	0	0	0	0	0	0
1156	Des Moines	SW 6th St and Thornton Ave	0	0	0	0	0	0	0	0
1157	Des Moines	SW 7th St and Thornton Ave	0	0	0	0	0	0	0	0
1158	Des Moines	SW 8th St and Thornton Ave	0	0	0	0	0	0	0	0
1160	Des Moines	SW 9th St and Wolcott Ave	0	0	0	0	0	0	0	0
1162	Des Moines	SW 9th St and Maish Ave	0	0	0	0	0	0	0	0
1163	Des Moines	SW 12th St and Wolcott Ave	0	0	0	0	0	0	0	0
1165	Des Moines	SW 9th St and Frederick Ave	0	0	0	0	0	0	0	0
1166	Des Moines	SW 9th St and Randolph St	0	0	0	0	0	0	0	0
1168	Des Moines	SW 10th St and Leland Ave	0	0	0	0	0	0	0	0
1169	Des Moines	SW 10th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	0	0
1173	Des Moines	SW 13th Pl and Leland Ave	0	0	0	0	0	0	0	0
1174	Des Moines	SW 13th St and Leland Ave	0	0	0	0	0	0	0	0
1175	Des Moines	SW 12th St and Leland Ave	0	0	0	0	0	0	0	0
1176	Des Moines	SW 12th ST and Randolph St	0	0	0	0	0	0	0	0
1177	Des Moines	SW 12th St and Payton Ave	0	0	0	0	0	0	0	0
1178	Des Moines	SW 12th St and Highview Dr	0	0	0	0	0	0	0	0
1179	Des Moines	SW 12th Ave and Wall Ave	0	0	0	0	0	0	0	0
1180	Des Moines	SW 12th Ave and Southlawn Dr	0	0	0	0	0	0	0	0
1181	Des Moines	SW 13th Pl and Southlawn Dr	0	0	0	0	0	0	0	0
1182	Des Moines	SW 13th Pl and Wall Ave	0	0	0	0	0	0	0	0
1183	Des Moines	SW 13th Pl and Payton Ave	0	0	0	0	0	0	0	0
1185	Des Moines	SW 7th St and Lally St	0	0	0	0	0	0	0	0
1187	Des Moines	SW 13th Pl and Porter Ave	0	0	0	0	0	0	0	0
1188	Des Moines	SW 14th St and Highview Dr	0	0	0	0	0	0	0	0
1189	Des Moines	SW 14th St and Southlawn Dr	0	0	0	0	0	0	0	0
1190	Des Moines	SW 14th St and Porter Avce	0	0	0	0	0	0	0	0
1191	Des Moines	SW 12th St and Porter Ave	0	0	0	0	0	0	0	0
1192	Des Moines	SW 14th St and Cutler Ave	0	0	0	0	0	0	0	0
1193	Des Moines	SW 14th St and Kenyon Ave	0	0	0	0	0	0	0	0
1194	Des Moines	SW 13th St and Cutler Ave	0	0	0	0	0	0	0	0
1195	Des Moines	SW 13th St and Kenyon Ave	0	0	0	0	0	0	0	0
1198	Des Moines	SW 10th St and Kenyon Ave	0	0	0	0	0	0	0	0
1199	Des Moines	SW 10th St and Frazier Ave	0	0	0	0	0	0	0	0
1200	Des Moines	SW 9th St and Spring St	0	0	0	0	0	0	0	0
1202	Des Moines	SW 3rd Pl and Kenyon Ave	0	0	0	0	0	0	0	0
1203	Des Moines	SW 3rd St and Porter Ave	0	0	0	0	0	0	0	0
1204	Des Moines	SW 5th St and Kenyon Ave	0	0	0	0	0	0	0	0
1206	Des Moines	SW 3rd Pl and Porter Ave	0	0	0	0	0	0	0	0
1207	Des Moines	SW 5th Pl and Porter Ave	0	0	0	0	0	0	0	0
1208	Des Moines	SW 7th St and Cutler Ave	0	0	0	0	0	0	0	0
1209	Des Moines	SW 7th St and Porter Ave	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1210	Des Moines	SW 7th St and Kenyon Ave	0	0	0	0	0	0	0	0
1211	Des Moines	SW 8th St and Porter Ave	0	0	0	0	0	0	0	0
1213	Des Moines	SW 8th St and Kenyon Ave	0	0	0	0	0	0	0	0
1215	Des Moines	SW 8th St and Payton Ave	0	0	0	0	0	0	0	0
1216	Des Moines	SW 7th St and Payton Ave	0	0	0	0	0	0	0	0
1217	Des Moines	SW 5th St and Payton Ave	0	0	0	0	0	0	0	0
1219	Des Moines	SW 3rd St and Payton Ave	0	0	0	0	0	0	0	0
1220	Des Moines	SW 2nd Ave and Payton Ave	0	0	0	0	0	0	0	0
1221	Des Moines	South Union and Hart Ave	0	0	0	0	0	0	0	0
1222	Des Moines	South Union and Payton Ave	0	0	0	0	0	0	0	0
1223	Des Moines	South Union and Leland Ave	0	0	0	0	0	0	0	0
1225	Des Moines	SW 2nd Ave and Leland Ave	0	0	0	0	0	0	0	0
1226	Des Moines	SW 2nd Ave and Lally St	0	0	0	0	0	0	0	0
1227	Des Moines	South Union and Lally St	0	0	0	0	0	0	0	0
1230	Des Moines	SW 3rd St and Lally St	0	0	0	0	0	0	0	0
1231	Des Moines	SW 3rd St and Leland Ave	0	0	0	0	0	0	0	0
1233	Des Moines	SW 5th St and Leland Ave	0	0	0	0	0	0	0	0
1234	Des Moines	SW 5th St and Lally St	0	0	0	0	0	0	0	0
1236	Des Moines	SW 6th St and Iowa 5/Army Post Ro	0	0	0	0	0	0	0	0
1237	Des Moines	SW 6th St and Lally St	0	0	0	0	0	0	0	0
1238	Des Moines	SW 6th St and Leland Ave	0	0	0	0	0	0	0	0
1239	Des Moines	SW 7th St and Leland Ave	0	0	0	0	0	0	0	0
1243	Des Moines	South Union and Philip St	0	0	0	0	0	0	0	0
1244	Des Moines	South Union and Emma Ave	0	0	0	0	0	0	0	0
1245	Des Moines	South Union and Maxwelton Dr	0	0	0	0	0	0	0	0
1247	Des Moines	SW 3rd St and Wall Ave	0	0	0	0	0	0	0	0
1248	Des Moines	SW 7th St and Wall Ave	0	0	0	0	0	0	0	0
1250	Des Moines	SW 8th St and Wall Ave	0	0	0	0	0	0	0	0
1252	Des Moines	SW 4th St and Wall Ave	0	0	0	0	0	0	0	0
1253	Des Moines	SW 2nd Ave and Porter Ave	0	0	0	0	0	0	0	0
1255	Des Moines	SW 2nd Ave and Wall Ave	0	0	0	0	0	0	0	0
1257	Des Moines	SW 3rd St and Kenyon Ave	0	0	0	0	0	0	0	0
1258	Des Moines	SW 3rd St and Diehl Ave	0	0	0	0	0	0	0	0
1260	Des Moines	37th St and Washington Ave	0	0	0	0	0	0	0	0
1261	Des Moines	Beaver Ave and Witmer Pkwy	0	0	0	0	0	0	0	0
1262	Des Moines	34th St and Witmer Pkwy	0	0	0	0	0	0	0	0
1265	Des Moines	33rd St and College Ave	0	0	0	0	0	0	0	0
1267	Des Moines	32nd St and College Ave	0	0	0	0	0	0	0	0
1268	Des Moines	32nd St and Clark St	0	0	0	0	0	0	0	0
1269	Des Moines	33rd St and Clark St	0	0	0	0	0	0	0	0
1270	Des Moines	34th St and Clark St	0	0	0	0	0	0	0	0
1271	Des Moines	31st St and Clark St	0	0	0	0	0	0	0	0
1275	Des Moines	30th St and Franklin Ave	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1276	Des Moines	30th St and Jefferson Ave	0	0	0	0	0	0	0	0
1277	Des Moines	31st St and Victoria Dr	0	0	0	0	0	0	0	0
1279	Des Moines	31st St and Lincoln Ave	0	0	0	0	0	0	0	0
1280	Des Moines	35th St and Hickman Rd	0	0	0	0	0	0	0	0
1282	Des Moines	32nd St and Hickman Rd	0	0	0	0	0	0	0	0
1284	Des Moines	30th St and Francis Ave	0	0	0	0	0	0	0	0
1285	Des Moines	32nd St and Francis Ave	0	0	0	0	0	0	0	0
1287	Des Moines	30th St and Allison Ave	0	0	0	0	0	0	0	0
1288	Des Moines	33rd St and Lincoln Ave	0	0	0	0	0	0	0	0
1289	Des Moines	33rd St and Hickman Rd	0	0	0	0	0	0	0	0
1291	Des Moines	34th St and Lincoln Ave	0	0	0	0	0	0	0	0
1292	Des Moines	37th St and Hickman Rd	0	0	0	0	0	0	0	0
1294	Des Moines	40th St and Hickman Rd	0	0	0	0	0	0	0	0
1295	Des Moines	36th St and Hickman Rd	0	0	0	0	0	0	0	0
1296	Des Moines	38th St and Hickman Rd	0	0	0	0	0	0	0	0
1297	Des Moines	39th St and Hickman Rd	0	0	0	0	0	0	0	0
1298	Des Moines	Beaver Ave and Allison Ave	0	0	0	0	0	0	0	0
1300	Des Moines	40th Pl/Marella T and Franklin Ave	0	0	0	0	0	0	0	0
1301	Des Moines	39th St and Franklin Ave	0	0	0	0	0	0	0	0
1303	Des Moines	37th St and Franklin Ave	0	0	0	0	0	0	0	0
1304	Des Moines	34th St and Franklin Ave	0	0	0	0	0	0	0	0
1305	Des Moines	36th St and Franklin Ave	0	0	0	0	0	0	0	0
1306	Des Moines	34th St and Jefferson Ave	0	0	0	0	0	0	0	0
1307	Des Moines	35th St and Franklin Ave	0	0	0	0	0	0	0	0
1308	Des Moines	34th St and Washington Ave	0	0	0	0	0	0	0	0
1309	Des Moines	36th St and Washington Ave	0	0	0	0	0	0	0	0
1310	Des Moines	36th St and Jefferson Ave	0	0	0	0	0	0	0	0
1311	Des Moines	38th St and Washington Ave/Mare	0	0	0	0	0	0	0	0
1312	Des Moines	30th St and Victoria Dr	0	0	0	0	0	0	0	0
1313	Des Moines	Forestdale Dr and Lanewood Dr	0	0	0	0	0	0	0	0
1315	Des Moines	Germania and Maquoketa Dr	0	0	0	0	0	0	0	0
1316	Des Moines	41st St and Germania	0	0	0	0	0	0	0	0
1317	Des Moines	41st St and College AVe	0	0	0	0	0	0	0	0
1318	Des Moines	41st St and Huntland	0	0	0	0	0	0	0	0
1319	Des Moines	41st St and Leonard Pl	0	0	0	0	0	0	0	0
1320	Des Moines	41st St and NW Drive	0	0	0	0	0	0	0	0
1323	Des Moines	Sani Dr and Beaver Ave	0	0	0	0	0	0	0	0
1324	Des Moines	Sani Dr and NW Drive	0	0	0	0	0	0	0	0
1325	Des Moines	Sani Dr and Huntland	0	0	0	0	0	0	0	0
1326	Des Moines	Huntland and NW Drive	0	0	0	0	0	0	0	0
1327	Des Moines	NW Driver and Beaver Ave	0	0	0	0	0	0	0	0
1328	Des Moines	38th St and Beaver Ave	0	0	0	0	0	0	0	0
1329	Des Moines	37th St and Beaver Ave	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1330	Des Moines	Clark St and Beaver Ave	0	0	0	0	0	0	0	0
1331	Des Moines	Nierob Court Dr and Washington Ave	0	0	0	0	0	0	0	0
1334	Des Moines	37th St and University Ave	0	0	0	0	0	0	0	0
1335	Des Moines	38th St and University Ave	0	0	0	0	0	0	0	0
1336	Des Moines	39th St and University Ave	0	0	0	0	0	0	0	0
1338	Des Moines	40th St and University Ave	0	0	0	0	0	0	0	0
1342	Des Moines	32nd St and Carpenter Ave	0	0	0	0	0	0	0	0
1343	Des Moines	31st St and Carpenter Ave	0	0	0	0	0	0	0	0
1344	Des Moines	30th St and Carpenter Ave	0	0	0	0	0	0	0	0
1345	Des Moines	31st St and Forest Ave	0	0	15880	0	0	0	0	0
1347	Des Moines	33rd St and Forest Ave	0	0	0	0	0	0	0	0
1350	Des Moines	Randall Place and Forest Ave	0	0	0	0	0	0	0	0
1351	Des Moines	Forestdale Dr and Forest Ave	0	0	0	0	0	0	0	0
1352	Des Moines	39th St and Forest Ave	0	0	0	0	0	0	0	0
1353	Des Moines	39th St and Hunter Ave	0	0	0	0	0	0	0	0
1356	Des Moines	39th St and Carpenter Ave	0	0	0	0	0	0	0	0
1357	Des Moines	40th St/Germania and Forest Ave	0	0	0	0	0	0	0	0
1359	Des Moines	41st Pl and Forest Ave	0	0	0	0	0	0	0	0
1361	Des Moines	41st St and Waveland Dr	0	0	0	0	0	0	0	0
1362	Des Moines	Germania and Waveland Dr	0	0	0	0	0	0	0	0
1365	Des Moines	40th St and Franklin Ave	0	0	0	0	0	0	0	0
1366	Des Moines	Sw 7th St and Rose Ave	0	0	0	0	0	0	0	0
1600	Des Moines	M.L. King Jr Pkwy and Mondamin Ave	0	0	0	0	0	0	0	0
1601	Des Moines	M.L. King Jr Pkwy and Meek Ave	0	0	0	0	0	0	0	0
1603	Des Moines	M.L. King Jr Pkwy and College Ave	0	0	0	0	0	0	0	0
1605	Des Moines	M.L. King Jr Pkwy and Jefferson Ave	0	0	0	0	0	0	0	0
1606	Des Moines	M.L. King Jr Pkwy and Allison Ave	0	0	0	0	0	0	0	0
1608	Des Moines	M.L. King Jr Pkwy and Francis Ave	0	0	0	0	0	0	0	0
1611	Des Moines	26th St and Payne Rd	0	0	0	0	0	0	0	0
1612	Des Moines	27th Pl and Bennett Ave	0	0	0	0	0	0	0	0
1614	Des Moines	27th St and Holcomb Ave	0	0	0	0	0	0	0	0
1616	Des Moines	27th St and Payne Rd	0	0	0	0	0	0	0	0
1617	Des Moines	27th St and Prospect Rd	0	0	0	0	0	0	0	0
1618	Des Moines	27th St and Sheridan Ave	0	0	0	0	0	0	0	0
1619	Des Moines	27th Pl and Sheridan Ave	0	0	0	0	0	0	0	0
1620	Des Moines	26th St and Holcomb Ave	0	0	0	0	0	0	0	0
1623	Des Moines	26th St and Lincoln Ave	0	0	0	0	0	0	0	0
1625	Des Moines	27th St and Allison Ave	0	0	0	0	0	0	0	0
1628	Des Moines	26th St and Wrenwood Dr	0	0	0	0	0	0	0	0
1630	Des Moines	27th St and Franklin Ave	0	0	0	0	0	0	0	0
1631	Des Moines	27th St and Witmer St	0	0	0	0	0	0	0	0
1632	Des Moines	27th St and Wrenwood Dr	0	0	0	0	0	0	0	0
1633	Des Moines	27th St and Moyer St	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1634	Des Moines	27th St and Mondamin Ave	0	0	0	0	0	0	0	0
1636	Des Moines	27th St and College Ave	0	0	0	0	0	0	0	0
1637	Des Moines	27th St and Meek Ave	0	0	0	0	0	0	0	0
1638	Des Moines	27th St and Euclid Ave	0	0	0	0	0	0	0	0
1648	Des Moines	27th Pl and Euclid Ave	0	0	0	0	0	0	0	0
1649	Des Moines	27th Pl and Amick Ave	0	0	0	0	0	0	0	0
1650	Des Moines	28th St and Euclid Ave	0	0	0	0	0	0	0	0
1653	Des Moines	27th St and Boston Ave	0	0	0	0	0	0	0	0
1654	Des Moines	27th St and Adams Ave	0	0	0	0	0	0	0	0
1656	Des Moines	25th St and Payne Rd	0	0	0	0	0	0	0	0
1657	Des Moines	25th St and Prospect Rd	0	0	0	0	0	0	0	0
1660	Des Moines	24th St and Holcomb Ave	0	0	0	0	0	0	0	0
1661	Des Moines	24th St and Bennett Ave	0	0	0	0	0	0	0	0
1662	Des Moines	M.L. King Jr Pkwy and Bennett Ave	0	0	0	0	0	0	0	0
1664	Des Moines	M.L. King Jr Pkwy and Adams Ave	0	0	0	0	0	0	0	0
1665	Des Moines	M.L. King Jr Pkwy and Payne Rd	0	0	0	0	0	0	0	0
1668	Des Moines	Glenarm Ct and Welbeck Rd	0	0	0	0	0	0	0	0
1669	Des Moines	Welbeck Rd and Boston Ave	0	0	0	0	0	0	0	0
1670	Des Moines	26th St and Boston Ave	0	0	0	0	0	0	0	0
1671	Des Moines	26th St and Ashby Ave	0	0	0	0	0	0	0	0
1672	Des Moines	26th Pl and Ashby Ave	0	0	0	0	0	0	0	0
1673	Des Moines	26th Pl and Boston Ave	0	0	0	0	0	0	0	0
1674	Des Moines	30th St (north) and Euclid Ave	0	0	0	0	0	0	0	0
1675	Des Moines	Oakcrest Dr and Euclid Ave	0	0	0	0	0	0	0	0
1676	Des Moines	30th St and Shady Oak Dr	0	0	0	0	0	0	0	0
1677	Des Moines	W 20th Pl and Meek Ave	0	0	0	0	0	0	0	0
1678	Des Moines	W 21st St and Meek Ave	0	0	0	0	0	0	0	0
1679	Des Moines	W 21st St and Mondamin Ave	0	0	0	0	0	0	0	0
1680	Des Moines	W 20th Pl and Mondamin Ave	0	0	0	0	0	0	0	0
1681	Des Moines	22nd St and Lincoln Ave	0	0	0	0	0	0	0	0
1682	Des Moines	23rd St and Lincoln Ave	0	0	0	0	0	0	0	0
1684	Des Moines	24th St and College Ave	0	0	0	0	0	0	0	0
1685	Des Moines	24th St and Franklin Ave	0	0	0	0	0	0	0	0
1686	Des Moines	24th Dr and Franklin Ave	0	0	0	0	0	0	0	0
1687	Des Moines	24th St and 24th Dr	0	0	0	0	0	0	0	0
1688	Des Moines	24th St and Washington Ave	0	0	0	0	0	0	0	0
1690	Des Moines	W 21st St and Washington Ave	0	0	0	0	0	0	0	0
1691	Des Moines	22nd St and Washington Ave	0	0	0	0	0	0	0	0
1692	Des Moines	23rd St and Washington Ave	0	0	0	0	0	0	0	0
1694	Des Moines	29th St and Clark St	0	0	0	0	0	0	0	0
1695	Des Moines	28th St and Clark St	0	0	0	0	0	0	0	0
1696	Des Moines	27th St and Clark St	0	0	0	0	0	0	0	0
1697	Des Moines	25th St and Clark St	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1698	Des Moines	24th St and Clark St	0	0	0	0	0	0	0	0
1699	Des Moines	22nd St and Clark St	0	0	0	0	0	0	0	0
1700	Des Moines	W 21st St and Clark St	0	0	0	0	0	0	0	0
1702	Des Moines	22nd St and Forest Ave	0	0	0	0	0	0	0	0
1703	Des Moines	23rd St and Forest Ave	0	0	0	0	0	0	0	0
1706	Des Moines	25th St and Carpenter Ave	0	0	0	0	0	0	0	0
1707	Des Moines	24th St and Carpenter Ave	0	0	0	0	0	0	0	0
1708	Des Moines	23rd St and Carpenter Ave	0	0	0	0	0	0	0	0
1709	Des Moines	22nd St and Carpenter Ave	0	0	0	0	0	0	0	0
1710	Des Moines	W 21st St and Carpenter Ave	0	0	0	0	0	0	0	0
1711	Des Moines	W 21st St and Carpenter Ave (nort	0	0	0	0	0	0	0	0
1715	Des Moines	26th St and University Ave	0	0	0	0	0	0	0	0
1716	Des Moines	27th St and University Ave	0	0	0	0	0	0	0	0
1718	Des Moines	23rd St (south) and Clark St	0	0	0	0	0	0	0	0
1721	Des Moines	28th St and Forest Ave	0	0	0	0	0	0	0	0
1722	Des Moines	29th St and Forest Ave	0	0	0	0	0	0	0	0
1724	Des Moines	36th St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1725	Des Moines	34th St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1726	Des Moines	34th St and Sheridan Ave	0	0	0	0	0	0	0	0
1727	Des Moines	33rd St and Sheridan Ave	0	0	0	0	0	0	0	0
1728	Des Moines	33rd St and Holcomb Ave	0	0	0	0	0	0	0	0
1729	Des Moines	30th St and Holcomb Ave	0	0	0	0	0	0	0	0
1731	Des Moines	30th St and Bennett Ave	0	0	0	0	0	0	0	0
1732	Des Moines	30th St and Mann Ave	0	0	0	0	0	0	0	0
1734	Des Moines	30th St and Prospect Dr	0	0	0	0	0	0	0	0
1737	Des Moines	30th St and Adams Ave	0	0	0	0	0	0	0	0
1738	Des Moines	30th St and Arnolds Rd	0	0	0	0	0	0	0	0
1739	Des Moines	30th St and Boston Ave	0	0	0	0	0	0	0	0
1740	Des Moines	30th St and Urbandale Ave	0	0	0	0	0	0	0	0
1741	Des Moines	35th St and Sheridan Ave	0	0	0	0	0	0	0	0
1742	Des Moines	34th St and Urbandale Ave	0	0	0	0	0	0	0	0
1743	Des Moines	36th St and Sheridan Ave	0	0	0	0	0	0	0	0
1745	Des Moines	35th St and Urbandale Ave	0	0	0	0	0	0	0	0
1747	Des Moines	39th St and 40th St	0	0	0	0	0	0	0	0
1748	Des Moines	39th St and Urbandale Ave	0	0	0	0	0	0	0	0
1749	Des Moines	Beaver Ave and Sheridan Ave	0	0	0	0	0	0	0	0
1752	Des Moines	Beaver Ave and Beaver Crest Dr	0	0	0	0	0	0	0	0
1753	Des Moines	Beaver Ave and Holcomb Ave	0	0	0	0	0	0	0	0
1754	Des Moines	40th Pl and Holcomb Ave	0	0	0	0	0	0	0	0
1755	Des Moines	40th St and Holcomb Ave	0	0	0	0	0	0	0	0
1756	Des Moines	39th St and Holcomb Ave	0	0	0	0	0	0	0	0
1757	Des Moines	38th St and Holcomb Ave	0	0	0	0	0	0	0	0
1758	Des Moines	37th St and Holcomb Ave	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
1759	Des Moines	36th St and Holcomb Ave	0	0	0	0	0	0	0	0
1760	Des Moines	35th St and Holcomb Ave	0	0	0	0	0	0	0	0
1761	Des Moines	34th St and Holcomb Ave	0	0	0	0	0	0	0	0
1762	Des Moines	38th St and Boston Ave	0	0	0	0	0	0	0	0
1763	Des Moines	40th St and Adams Ave	0	0	0	0	0	0	0	0
1764	Des Moines	39th St and Adams Ave	0	0	0	0	0	0	0	0
1765	Des Moines	40th Pl and Adams Ave	0	0	0	0	0	0	0	0
1766	Des Moines	Beaver Ave and Adams Ave	0	0	0	0	0	0	0	0
1767	Des Moines	Beaver Ave and Fagen Dr	0	0	0	0	0	0	0	0
1768	Des Moines	38th St and Fagen Dr	0	0	0	0	0	0	0	0
1769	Des Moines	37th St and Adams Ave	0	0	0	0	0	0	0	0
1770	Des Moines	36th St and Adams Ave	0	0	0	0	0	0	0	0
1773	Des Moines	34th St and Adams Ave	0	0	0	0	0	0	0	0
1774	Des Moines	35th St and Adams Ave	0	0	0	0	0	0	0	0
1775	Des Moines	34th Pl and Adams Ave	0	0	0	0	0	0	0	0
1777	Des Moines	36th St and Linda Circle	0	0	0	0	0	0	0	0
1778	Des Moines	36th St and Davisson Rd	0	0	0	0	0	0	0	0
1780	Des Moines	38th St and Davisson Rd	0	0	0	0	0	0	0	0
1781	Des Moines	Beaver Ave and Maryland Pike	0	0	0	0	0	0	0	0
1782	Des Moines	40th St and Clinton Ave	0	0	0	0	0	0	0	0
1783	Des Moines	38th St and Clinton Ave	0	0	0	0	0	0	0	0
1785	Des Moines	38th St and Amick Ave (south)	0	0	0	0	0	0	0	0
1787	Des Moines	40th Pl and Ovid Ave	0	0	0	0	0	0	0	0
1788	Des Moines	40th Pl and Ashby Ave	0	0	0	0	0	0	0	0
1790	Des Moines	Wallace Lane (eas and Ashby Ave	0	0	0	0	0	0	0	0
1791	Des Moines	Beaver Ave and Ashby Ave	0	0	0	0	0	0	0	0
1793	Des Moines	Beaver Ave and Ovid Ave	0	0	0	0	0	0	0	0
1794	Des Moines	Beaver Ave and Amick Ave	0	0	0	0	0	0	0	0
1795	Des Moines	Beaver Ave and Euclid Ave	0	0	0	0	0	0	0	0
1796	Des Moines	Beaver Ave and Clinton Ave	0	0	0	0	0	0	0	0
1797	Des Moines	42nd St and Clinton Ave	0	0	0	0	0	0	0	0
1798	Des Moines	42nd St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1799	Des Moines	41st St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1800	Des Moines	40th St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1801	Des Moines	39th St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
1803	Des Moines	37th St and US 6/Douglas Ave	0	0	0	0	0	0	0	0
2001	Des Moines	E 2nd St and Court Ave	0	0	0	0	0	0	0	0
2002	Des Moines	E 1st St and Court Ave	0	0	0	0	0	0	0	0
2003	Des Moines	1st St and Walnut St	0	0	0	0	0	0	0	0
2005	Des Moines	E 2nd St and Locust St	0	0	0	0	0	0	0	0
2008	Des Moines	E 3rd St and Locust St	0	0	0	0	0	0	0	0
2010	Des Moines	E 5th St and Court Ave	0	0	0	0	0	0	0	0
2011	Des Moines	E 5th St and Walnut St	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
2015	Des Moines	E 2nd St and Walnut St	0	0	0	0	0	0	0	0
2017	Des Moines	E 1st St and Walnut ST	0	0	0	0	0	0	0	0
2019	Des Moines	Watson Powell/Keo and Grand Ave	0	0	0	0	0	0	0	0
2022	Des Moines	11th St and High St	0	0	0	0	0	0	0	0
2024	Des Moines	10th St and Cherry St	0	0	0	0	0	0	0	0
2026	Des Moines	12th St and Walnut St	0	0	0	0	0	0	0	0
2027	Des Moines	12th St and Mulberry St	0	0	0	0	0	0	0	0
2028	Des Moines	11th St and Cherry St	0	0	0	0	0	0	0	0
2029	Des Moines	12th St and Cherry St	0	0	0	0	0	0	0	0
2030	Des Moines	13th St and Mulberry St	0	0	0	0	0	0	0	0
2032	Des Moines	16th St and Walnut St	0	0	0	0	0	0	0	0
2037	Des Moines	16th St and Ingersoll Ave	0	0	0	0	0	0	0	0
2039	Des Moines	13th St and High St	0	0	0	0	0	0	0	0
2041	Des Moines	E 7th St and Court Ave	0	0	0	0	0	0	0	0
5001	Ames	Duff Ave. and Ken Maril Rd.	0	0	0	0	0	0	0	0
5003	Ames	Duff Ave. and Jewell Dr	0	0	0	0	0	0	0	0
5004	Ames	Duff Ave. and Crystal S	0	0	0	0	0	0	0	0
5005	Ames	State and Oakwood Rd.	0	0	0	0	0	0	0	0
5006	Ames	Cedar Lane and Oakwood Rd.	0	0	0	0	0	0	0	0
5007	Ames	White Oak and Oakwood Rd.	0	0	0	0	0	0	0	0
5008	Ames	Greenhill Dr. and Oakwood Rd.	0	0	0	0	0	0	0	0
5009	Ames	Elwood Dr. and Airport Rd.	0	0	0	0	0	0	0	0
5010	Ames	N. Loop Drive Wes and Airport Rd.	0	0	0	0	0	0	0	0
5011	Ames	State and Dartmouth	0	0	0	0	0	0	0	0
5012	Ames	Elwood Dr. and Greenhill Dr.	0	0	0	0	0	0	0	0
5013	Ames	N. Loop Drive Eas and Airport Rd.	0	0	0	0	0	0	0	0
5014	Ames	S. Riverside and Airport Rd.	0	0	0	0	0	0	0	0
5016	Ames	State and Meadow Glen	0	0	0	0	0	0	0	0
5017	Ames	Elwood Dr. and Ironwood	0	0	0	0	0	0	0	0
5021	Ames	Coneflower Ct. and Mortenson Rd.	0	0	0	0	0	0	0	0
5022	Ames	Bluestem Ct. and Mortenson Rd.	0	0	0	0	0	0	0	0
5023	Ames	South Dakota and Steinbeck	0	0	0	0	0	0	0	0
5026	Ames	Duff Ave. and Chestnut	0	0	0	0	0	0	0	0
5028	Ames	State and Mortenson Rd.	0	0	270	145	0	0	0	0
5032	Ames	South Dakota and Clemens	0	0	0	0	0	0	0	0
5037	Ames	South Dakota and Todd Dr.	0	0	0	0	0	0	0	0
5039	Ames	South Dakota and Lincoln Swing	0	0	0	0	0	0	0	0
5047	Ames	Manning and Lincoln Way	0	0	0	0	0	0	0	0
5051	Ames	Sheldon and Lincoln Way	175	0	0	0	0	0	0	0
5053	Ames	Welch Ave. and Lincoln Way	40	0	0	0	0	0	0	0
5060	Ames	Riverside and Lincoln Way	0	0	0	0	0	0	0	0
5061	Ames	Russell and Lincoln Way	0	0	0	0	0	0	0	0
5073	Ames	Duff Ave. and 3rd St.	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
5074	Ames	North Dakota and West Bend	0	0	0	0	0	0	0	0
5078	Ames	North Dakota and Delaware	0	0	0	0	0	0	0	0
5080	Ames	Clark and 6th St.	0	0	0	0	0	0	0	0
5081	Ames	Burnett and 6th St.	0	0	0	0	0	0	0	0
5082	Ames	Kellogg and 6th St.	0	0	0	0	0	0	0	0
5083	Ames	Douglas and 6th St.	0	0	0	0	0	0	0	0
5085	Ames	Grand and 7th St.	0	0	0	0	0	0	0	0
5086	Ames	Wilson and 7th St.	0	0	0	0	0	0	0	0
5087	Ames	Clark and 7th St.	0	0	0	0	0	0	0	0
5088	Ames	Burnett and 7th St.	0	0	0	0	0	0	0	0
5089	Ames	Kellogg and 7th St.	0	0	0	0	0	0	0	0
5090	Ames	Douglas and 7th St.	0	0	0	0	0	0	0	0
5091	Ames	Duff Ave. and 7th St.	0	0	0	0	0	0	0	0
5092	Ames	North Dakota and Phoenix	0	0	0	0	0	0	0	0
5094	Ames	Wilson and 8th St.	0	0	0	0	0	0	0	0
5095	Ames	Clark and 8th St.	0	0	0	0	0	0	0	0
5096	Ames	Burnett and 8th St.	0	0	0	0	0	0	0	0
5097	Ames	Kellogg and 8th St.	0	0	0	0	0	0	0	0
5098	Ames	Douglas and 8th St.	0	0	0	0	0	0	0	0
5099	Ames	Duff Ave. and 8th St.	0	0	0	0	0	0	0	0
5101	Ames	Wilson and 9th St.	0	0	0	0	0	0	0	0
5102	Ames	Clark and 9th St.	0	0	0	0	0	0	0	0
5103	Ames	Burnett and 9th St.	0	0	0	0	0	0	0	0
5104	Ames	Kellogg and 9th St.	0	0	0	0	0	0	0	0
5105	Ames	Douglas and 9th St.	0	0	0	0	0	0	0	0
5106	Ames	Duff Ave. and 9th St.	0	0	0	0	0	0	0	0
5108	Ames	Wilson and 10th St.	0	0	0	0	0	0	0	0
5109	Ames	Clark and 10th St.	0	0	0	0	0	0	0	0
5110	Ames	Burnett and 10th St.	0	0	0	0	0	0	0	0
5111	Ames	Kellogg and 10th St.	0	0	0	0	0	0	0	0
5112	Ames	Douglas and 10th St.	0	0	0	0	0	0	0	0
5113	Ames	Duff Ave. and 10th St.	0	0	0	0	0	0	0	0
5114	Ames	North Dakota and Ross Rd.	0	0	0	0	0	0	0	0
5115	Ames	Grand and 11th St.	0	0	0	0	0	0	0	0
5116	Ames	Wilson and 11th St.	0	0	0	0	0	0	0	0
5117	Ames	Clark and 11th St.	0	0	0	0	0	0	0	0
5118	Ames	Burnett and 11th St.	0	0	0	0	0	0	0	0
5119	Ames	Kellogg and 11th St.	0	0	0	0	0	0	0	0
5122	Ames	Wilson and 12th St.	0	0	0	0	0	0	0	0
5123	Ames	Clark and 12th St.	0	0	0	0	0	0	0	0
5124	Ames	Burnett and 12th St.	0	0	0	0	0	0	0	0
5125	Ames	Kellogg and 12th St.	0	0	0	0	0	0	0	0
5126	Ames	Duff Ave. and 12th St.	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
5127	Ames	North Dakota and Ontario	0	0	0	0	0	0	0	0
5128	Ames	Woodstock and Ontario	0	0	0	0	0	0	0	0
5129	Ames	Arizona and Ontario	0	0	0	0	0	0	0	0
5130	Ames	Alberta and Ontario	0	0	0	0	0	0	0	0
5131	Ames	Alabama and Ontario	0	0	0	0	0	0	0	0
5132	Ames	Garfield and Ontario	0	0	0	0	0	0	0	0
5133	Ames	School and Ontario	0	0	0	0	0	0	0	0
5134	Ames	Michigan and Ontario	0	0	0	0	0	0	0	0
5135	Ames	Minnesota and Ontario	0	0	0	0	0	0	0	0
5136	Ames	Wisconsin and Ontario	0	0	0	0	0	0	0	0
5137	Ames	Scott and Ontario	0	0	0	0	0	0	0	0
5138	Ames	Iowa and Ontario	0	0	0	0	0	0	0	0
5139	Ames	Ontario Circle and Ontario	0	0	0	0	0	0	0	0
5141	Ames	Crescent and 13th St.	0	0	0	0	0	0	0	0
5144	Ames	Curtiss and 13th St.	0	0	0	0	0	0	0	0
5145	Ames	Marston and 13th St.	0	0	0	0	0	0	0	0
5146	Ames	Roosevelt and 13th St.	0	0	0	0	0	0	0	0
5147	Ames	Harding and 13th St.	0	0	0	0	0	0	0	0
5149	Ames	Wilson and 13th St.	0	0	0	0	0	0	0	0
5150	Ames	Clark and 13th St.	0	0	0	0	0	0	0	0
5151	Ames	Burnett and 13th St.	0	0	0	0	0	0	0	0
5156	Ames	Burnett and 14th St.	0	0	0	0	0	0	0	0
5157	Ames	Kellogg and 14th St.	0	0	0	0	0	0	0	0
5158	Ames	Douglas and 14th St.	0	0	0	0	0	0	0	0
5159	Ames	Duff Ave. and 14th St.	0	0	0	0	0	0	0	0
5160	Ames	Carroll and 14th St.	0	0	0	0	0	0	0	0
5161	Ames	Stafford and 14th St.	0	0	0	0	0	0	0	0
5162	Ames	Maxwell and 14th St.	0	0	0	0	0	0	0	0
5163	Ames	Glendale and 14th St.	0	0	0	0	0	0	0	0
5164	Ames	Linden and 14th St.	0	0	0	0	0	0	0	0
5166	Ames	Wilson and 15th St.	0	0	0	0	0	0	0	0
5167	Ames	Clark and 15th St.	0	0	0	0	0	0	0	0
5168	Ames	Burnett and 15th St.	0	0	0	0	0	0	0	0
5169	Ames	Kellogg and 15th St.	0	0	0	0	0	0	0	0
5170	Ames	Douglas and 15th St.	0	0	0	0	0	0	0	0
5171	Ames	Duff Ave. and 15th St.	0	0	0	0	0	0	0	0
5174	Ames	Wilson and 16th St.	0	0	0	0	0	0	0	0
5175	Ames	Clark and 16th St.	0	0	0	0	0	0	0	0
5176	Ames	Burnett and 16th St.	0	0	0	0	0	0	0	0
5177	Ames	Kellogg and 16th St.	0	0	0	0	0	0	0	0
5178	Ames	Douglas and 16th St.	0	0	0	0	0	0	0	0
5180	Ames	Carroll and 16th St.	0	0	0	0	0	0	0	0
5181	Ames	Stafford and 16th St.	0	0	0	0	0	0	0	0

Table C.1. (continued)

ID	City	Literal Description	85-89	86-90	87-91	88-92	91-95	92-96	94-98	95-99
5182	Ames	Maxwell and 16th St.	0	0	0	0	0	0	0	0
5183	Ames	Carr Dr. and 16th St.	0	0	0	0	0	0	0	0
5184	Ames	Glendale and 16th St.	0	0	0	0	0	0	0	0
5185	Ames	Grand and Murray	0	0	0	0	0	0	0	0
5186	Ames	Duff Ave. and Carroll	0	0	0	0	0	0	0	0
5187	Ames	Crestwood and Carr Dr.	0	0	0	0	0	0	0	0
5188	Ames	Duff Ave. and O'Neill	0	0	0	0	0	0	0	0
5189	Ames	Grand and 18th St.	0	0	0	0	0	0	0	0
5192	Ames	Duff Ave. and Broadmoor	0	0	0	0	0	0	0	0
5193	Ames	Duff Ave. and Douglas	0	0	0	0	0	0	0	0
5194	Ames	Grand and 24th St.	193	0	0	0	0	0	0	0
5196	Ames	Duff Ave. and Northwood (South)	0	0	0	0	0	0	0	0
5197	Ames	Hoover and 30th St.	0	0	0	0	0	0	0	0
5198	Ames	Northwestern and 30th St.	0	0	0	0	0	0	0	0
5199	Ames	Regency Ct. and 30th St.	0	0	0	0	0	0	0	0
5200	Ames	Ferndale and 30th St.	0	0	0	0	0	0	0	0
5203	Ames	Grove and 30th St.	0	0	0	0	0	0	0	0
5204	Ames	Kellogg and 30th St.	0	0	0	0	0	0	0	0
5205	Ames	Northwood (North) and 30th St.	0	0	0	0	0	0	0	0
5206	Ames	Duff Ave. and Briggs	0	0	0	0	0	0	0	0
5207	Ames	Hoover and Truman	0	0	0	0	0	0	0	0
5208	Ames	Hoover and Wheeler	0	0	0	0	0	0	0	0
5209	Ames	Hoover and Buchanan	0	0	0	0	0	0	0	0
5211	Ames	Hoover and Jefferson	0	0	0	0	0	0	0	0
5212	Ames	Hoover and Bloomington	0	0	0	0	0	0	0	0
5213	Ames	Roy Key and Bloomington	0	0	0	0	0	0	0	0
5214	Ames	Grand and Bloomington	0	0	0	0	0	0	0	0
5201	Ames	Roy Key and 30th St.	0	0	0	0	0	0	5974	0
2000	Des Moines	E 3rd St and Court Ave	0	0	0	0	0	0	7335	0
1246	Des Moines	SW 9th St and Wall Ave	0	0	0	0	0	0	7743	0
5024	Ames	Ash Ave. and Mortenson Rd.	0	0	0	0	0	0	7787	0
150	Des Moines	27th St and Forest Ave	0	0	0	0	0	0	7833	0
2034	Des Moines	16th St and Grand Ave	0	0	0	0	0	0	8843	0
5063	Ames	Maple and Lincoln Way	0	0	0	0	0	0	8947	0
5120	Ames	Duff Ave. and 11th St.	0	0	4393	0	0	0	9341	0
2033	Des Moines	16th St and Locust St	0	0	0	0	0	0	9438	0
1098	Des Moines	SW 9th St and Philip St	0	0	0	0	0	0	9764	0
5076	Ames	Grand and 5th St.	0	0	0	0	0	0	9775	0

APPENDIX D. AMES/DES MOINES INTERSECTION PAST HES/TSIP PROJECTS

The Traffic Safety Improvement Program (TSIP) projects in Des Moines and Ames from 1990 to the present are shown in Figure D.1.

Figure D.1. Traffic Safety Improvement Program (TSIP) projects

Fiscal Year	City	Route	Location	Project Number	Comments	Cost Approved
1990	Des Moines		Harding/19th from University to Clark	CS-TSF-1945(2)	signals	$300,000
1990	Des Moines	US 6	Hickman and Merle Hay Rd	CS-TSF-1945(3)	const/signals	$165,500
1990	Des Moines	US 6	Merle Hay Rd and Urbandale	CS-TSF-1945(3)	signal upgrade	$34,500
1990	Des Moines	IA 415	at NW Aurora Ave	L-TSF-0077(2)	signals	$60,000
1990	Des Moines		NW 6th Dr and Aurora	FM-TSF-0077(3)	reconstruct	$256,200
1991	Des Moines	US 69	at NE 66th Ave	SN-TSF-3403(5)	reconstruct	$500,000
1991	Des Moines		2nd Ave and University	CS-TSF-1945(6)	signal upgrade	$300,000
1991	Des Moines		NW Beaver and Acorn Valley	SN-TSF-3367(4)	shoulders/slopes	$65,000
1991	Des Moines	I-235	at E6th and WB ramps	CS-TSF-1945(4)	signal	$35,000
1991	Des Moines		University at 9th and 13th	CS-TSF-1945(5)	signals - upgrade	$360,000
1991	Des Moines		Grand Ave at E1st, 6th, 9th, 12th	CS-TSF-1945(5)	signals - upgrade	$360,000
1991	Des Moines		2nd Ave at Holcomb and York	CS-TSF-1945(5)	signals - upgrade	$360,000
1991	Des Moines		6th at Holcomb, College, and Forest	CS-TSF-1945(5)	signals - upgrade	$360,000
1991	Des Moines		Court at E 6th	CS-TSF-1945(5)	signals - upgrade	$360,000
1992	Ames		Lincoln Way at Dayton Ave	CS-TSF-0155(2)	add signals/bay	$440,000
1992	Ames		Lincoln Way at Hyland Ave	CS-TSF-0155(3)	add signals	$60,000
1992	Des Moines		NW 6th from NW 16th to NW 69th	FM-TSF-0077(7)	rebuild	$368,000
1992	Des Moines		Locust/Grand at 10th, 12th, 13th, 15th, and 17th	CS-TSF-1945(7)	upgrade signals	$251,000
1993	Ames	US 69	S Duff, Squaw Creek to 3rd Ave	CS-TSF-0155(5)	add 5th lane	$500,000
1994	Des Moines	US 65/69	SE 14th at Park Ave	CS-TSF-1945(10)	crossroad lanes	$150,000
1994	Des Moines	Iowa 5	Army Post at Indianola Ave	CS-TSF-1945(11)	add lanes/signals	$500,000
1994	Des Moines		NE Broadway at NE 3rd	FM-TSF-0077(1)	signals	$185,000
1994	Des Moines		NE Broadway at NE 22nd	FM-TSF-0077(1)	signals	$185,000
1994	Des Moines	IA 415	NE 2nd at NW Broadway	FM-TSF-0077(1)	signals	$185,000
1994	Des Moines		University - Penn Ave to E 9th	CS-TSF-1945(1)	reconstruct	$350,000
1994	Des Moines	IA 28	at Merle Hay	CS-TSF-0077(9)	crossroad lanes/median	$200,000
1995	Des Moines		NW Beaver at curve N of 112th Ave	FM-TSF-0077(52)	rev shoulder/slope	$89,600
1995	Des Moines		E 4th/6th at Walnut/Locust	CS-TSF-1945(12)	signals	$150,000
1996	Ames		S 3rd at Walnut	CS-TSF-0155(13)		$75,000
1998	Des Moines		University at 19th St and ML King Pkwy	CS-TSF-1945(37)-85-77	signals upgrade	$80,000
1998	Des Moines		31st St and Kingman Blvd	CS-TSF-1945(36)-85-77	turn bays and signals	$135,000
1999	Des Moines	IA 28	Merle Hay Rd, Douglas to Ovid	CS-TSF-1945(44)	add 5th lane/center turning lane	$500,000
1999	Des Moines		55th St and University	CS-TSF-1945(43)	street closure	$100,000
2000	Ames	US 30	EB ramp and Elwood Dr	CS-TSF-0185(28)-85-85	new traffic signal	$60,217

Figure D.1. (continued)

Fiscal Year	City	Route	Location	Project Number	Comments	Cost Approved
2000	Des Moines		University at 42nd and 3100-4800 blocks	CS-TSF-1945(50)	restripe, upgrade signal	$200,000
2000	Des Moines	IA 28	at McKinley Ave	CS-TSF-1945(49)	new signal	$100,000
2000	Des Moines		E 6th and University Ave	CS-TSF-1945(48)	revise bridge rail for sight distance	$382,000
2000	Des Moines	various	Army Post/E University/Euclid/Douglas/Hubbell	CS-TSF-1945(47)-85-77	backplates and ALL APPROACHES	$50,000
2001	Ames		13th St and Northwestern	CS-TSF-0155(633)-85-85	signalize	$66,255
2001	Des Moines		Ingersoll and ML King Jr Pkwy	CS-TSF-1945(654)-85-77	widening/alignment, new signals	$500,000
2001	Des Moines		East 33rd and Hubbell Ave	CS-TSF-1945(655)-87-77	widening, resignalize	$500,000
2001	Des Moines		SW 42nd St and Park Ave	CS-TSF-1945(656)-85-77	left turning lane, signalize	$50,000
2001	Des Moines	US 6	50th St and Douglas Ave	CS-TSF-1945(657)-85-77	resignalize	$250,000
2001	Des Moines	US 69	E 14th St and University	CS-TSF-1945(658)-85-77	new traffic signals	$75,000
2003	Des Moines		Ingersoll at 28th, 31st, and 25th	CS-TSF-1945(671)-85-77	add left turn lanes, upgrade signals	$183,200
2003	Des Moines		42nd St and Grand/Ingersoll	CS-TSF-1945(672)-85-77	add turn lanes, rephase signals	$125,000
2003	Des Moines		Park from SW 42nd to SW 56th	CS-TSF-1945(673)-85-77	add center left turn lane	$155,000
2003	Des Moines		Hickman and 30th St	CS-TSF-1945(674)-85-77	upgrade signals	$55,000
2004	Ames	US 69	Lincoln Way at Kellogg	CS-TSF-0155(643)-85-85	signals	$66,905
2004	Des Moines	US 69	around E Indianola	CS-TSF-1945(683)-85-77	improve	$150,000
2004	Des Moines	IA 28	at Aurora	CS-TSF-1945(682)-85-77	upgrade signals	$37,600

The Highway Evaluation System (HES) projects in Des Moines and Ames from 1990 to the present are shown in Table D.2.

Table D.2. Highway Evaluation System (HES) projects

City	Route	Location	Project Number	Estimated Cost
Ames	US 30	at Dayton Rd	HES-30-5-(57)	$3,906,000
Ames	US 69	at 24th St	STP-69-5-(46)	$556,000
Ames	US 69	S Duff at 16th	HES-69-5-(77)-2H-85	$156,000
Des Moines	IA 163	at Jct IA 46 (30th St)	HES-163-1-(31)	$1,461,000
Des Moines	IA 163	from Hubble to 30th St	HES-163-1-(35)	$2,721,000
Des Moines	IA 5	at SE 5th St	HES-5-5-(20)	$450,000
Des Moines	US 65/69	Int E 15th and Grand	HES-65-4-(51&52)	$300,000
Des Moines	US 65/69	at Maple	HES-65-4-(55)	$685,000
Des Moines	US 65/69	Delaware and Euclid	HES-6-4-(99)-2H-77	$2,800,000
Des Moines	IA 5	at Chaffee/S Union	HES-5-5-(32)-2H-77	$1,361,000
Des Moines	US 65	at Guthrie	HES-65-4-(61)-SH-77	$597,000
Des Moines	IA 163	University and Williams	(HES) NHS-163-1-(52)-SH-77	$1,500,000
Des Moines	IA 28	63rd St and University Ave	HES-28-2-(22)-2H-77	$3,100,000
Des Moines	US 69	at Aurora	(HES) STP-69-4-(57)-2H-77	$950,000
Des Moines		2nd from Des Moines River to New York	STP-U-1945(3)	$336,000

Table D.2. (continued)

City	Route	Location	Project Number	Estimated Cost
Des Moines	US 65	at Watrous	HES-65-4-(34)	$310,000
Des Moines	US 65	at McKinley	HES-65-4-(42)	$290,000
Des Moines	US 65	Glenwood Dr to Des Moines River	HES-65-4-(36)	$2,650,000
Des Moines	US 65	E 14th at Grand	HES-65-4-(49)	$47,000
Des Moines	US 65	E 15th at Grand	HES-65-4-(51)	$147,000
Des Moines	US 65	E 15th at Grand	HES-65-4-(52)	$51,000
Des Moines	IA 5	at SW 9th St	HES-5-5-(13)	$200,000
Des Moines	US 6	Beaver and Douglas	HES-6-4-(129)-2H-77	$2,100,000
Des Moines	US 6/IA 28	Merle Hay, Ovid to Douglas	HES-6-4-(128)-2H-77	$1,370,000
Des Moines		SW 9th and Porter		$1,625,000
Des Moines	US 69	at Guthrie	HES-69-4-(61)-2H-77	$1,100,000

APPENDIX E. STAKEHOLDERS

Several stakeholders who may hold interest in the application and improvement of safety improvement candidate location lists are described in the figures within this appendix. The discernment of interest is left to the reader.

Shown in Figure E.1., there are several federal government traffic safety-related agencies. Some of these agencies are more directly connected to the transportation network than others. However, each has a responsibility to improve safety on the network, whether by system improvements or identification of problems.

United States Department of Transportation (USDOT)

Primary federal agency concerned with various aspects of highway transportation. Several agencies that focus on different aspects of highway transportation fit within the organizational structure of USDOT, including the Federal Highway Administration (FHWA), the National Highway Traffic Safety Administration (NHTSA), the Federal Motor Carrier Safety Administration (FMSCA), the Federal Railroad Administration (FRA), the Bureau of Transportation Statistics (BTS), the Federal Transit Authority (FTA), the Surface Transportation Board (STB), the National Highway Institute (NHI), and the Research and Special Programs Administration (RSPA).

Federal Highway Administration (FHWA)

Responsible for highway travel within the United States. They manage a wide variety of concerns related to this responsibility including many involved with highway safety. The research division of FHWA is the Turner-Fairbank Highway Research Center (TFHRC) and the training division is the National Highway Institute (NHI). TFHRC administers many ongoing projects to improve highway safety analyses and foster gains in effective knowledge. These projects include the Interactive Highway Safety Design Model (IHSDM), Intelligent Transportation Systems (ITS) research, the Highway Safety Information System (HSIS), the Comprehensive Highway Safety Improvement Model (CHSIM) (recently renamed SafetyAnalyst), the Traffic Software Integrated System (TSIS), and Intersection safety studies. NIH provides training resources, materials, and educational opportunities, including those specifically related to safety, to the surface transportation community.

National Highway Traffic Safety Administration (NHTSA)

Considers a wide variety of safety concerns, including those concerning passenger vehicles, motor carriers, bicycles, and pedestrians. Oversees the national Graduated Driver's License (GDL) program, the Vehicle Research and Test Center (VRTC), and safety data collection guidelines such as the Model Minimum Uniform Crash Criteria (MMUCC), the former Critical Automated Data Reporting Elements (CADRE) (1991), and national standards such as ANSI D16.1/ANSI D20. Two divisions of NHTSA are the National Center for Statistics and Analysis (NCSA) and the Crash Investigation Division (CID). NCSA manages many data-related programs, including the National Automotive Sampling System (NASS), the Statewide Data System (SDS), and the Crash Outcome Data Evaluation System (CODES). CID administers the Crashworthiness Data System (CDS) and the General Estimates System (GES), which both contribute to NASS. CID also administers the Special Crash Investigation (SCI) program.

Federal Motor Carrier Safety Administration (FMSCA)

Primarily concerned with commercial motor vehicle related crashes. FMCSA has recently instituted a new program, jointly administered with NHTSA, to track commercial motor vehicle related crashes, much like FARS, called the Commercial Vehicle Accident Reporting Systems (CVARS). FMSCA also has a motor carrier safety monitoring system called the Safety and Fitness Electronic Records System (SAFER). Using this data and methods that identify causal factors and locations of high concern, FMCSA seeks to reduce the number and severity of commercial motor vehicle related crashes throughout the nation and to identify points of concern for motor vehicle traffic safety.

Federal Railroad Administration (FRA)

Tracks train derailments and train-motor-vehicle crashes. Crash histories for rail-highway crossing points are available online.

Bureau of Transportation Statistics (BTS)

Administers several transportation-related data initiatives, including several that are safety related. The Data Gaps Project, just initiated, is attempting to address unasked and unanswered questions related to transportation in a collaborative way. The BTS Geographic Information Services provide a national resource for spatial data and GIS-T information related to transportation, including download centers. BTS also provides grants for data and statistical improvement within transportation, publishes the Journal of Transportation and Statistics, administers Statistical Policy and Research, and compiles and analyzes statistics related to transportation, including those that discern whether the transportation system is improving or declining.

Federal Transit Authority (FTA)

Administers several transit related projects, including some related to transit safety.

Surface Transportation Board (STB)

Holds jurisdiction over certain surface transportation economic regulatory matters, mainly related to rail and motor carrier regulation.

Research and Special Programs Administrationn (RSPA)

Administers many research related programs within the US DOT, including some that relate directly to safety. RSPA offices include Emergency Transportation, HAZMAT Safety, Innovation, Research, & Education, Transportation Safety Institute, and the Volpe Center. RSPA also oversees the University Transportation Centers (UTC).

National Transportation Safety Bureau (NTSB)

Concerned with all aspects of transportation safety, include highway safety. Maintains materials related to legal opinions, crash records, studies, and special topics. Promotes highway safety initiatives such as seat belt usage laws, commercial vehicle and bus safety, youth highway safety, and child restraint issues. Schedules public hearings related to these issues.

National Research Council (NRC)

A division of the National Academy of Science (NAS). Oversees the Transportation Research Board (TRB) which, in its turn oversees the National Cooperative Highway Research Program (NCHRP). There are numerous past and present NCHRP projects related to legal liability, statistics, and a variety of safety concerns, including intersections, evaluation, and locations for potential safety improvement. Many recent TRB publications have addressed the topic of high crash locations, crash black spots, or sites with promise. Also, TRB has several committees that address various aspects of highway safety, including:

- A3A05: Railroad-Highway Grade Crossings,
- A3B01: Transportation Safety Management,
- A3B05: Safety Data, Analysis, and Evaluation,
- A3B13: Safe Mobility of Older Persons, and
- A3B57: Task Force on Truck and Bus Safety.

Figure E.1. Federal government traffic safety-related agencies

Shown in Figure E.2. are state government traffic safety-related agencies. These agencies may have different names in each state but typically all three exist. Like the federal agencies, these state agencies have a responsibility to improve the safety of the transportation network.

Departments of Transportation (DOT)

Administer state intermodal transportation concerns. Though state transportation departments might have an office whose focal point is safety, many different divisions might also be concerned with transportation safety including design, construction, maintenance, motor vehicle, planning, and districts. A safety office would primarily be concerned with promoting safety throughout the DOT structure, with some specific duties related to identification of sites of concern, reviewing projects from a safety perspective, and assisting/educating the disparate entities within DOT that have alternate concerns. Design and planning can greatly enhance highway safety by considering safety in their projects and designs. Construction can ensure that highways are built to current standards. Maintenance, who are most likely to travel the state roadways through their normal activities, can identify potential concerns. Additionally, during snowfall, maintenance activities clear the road. Motor vehicle, through review of driver and vehicle licensing records, can identify and remove bad drivers and vehicles from the road. Districts might contain all these responsibilities for their area, relying on the central offices for assistance and advice.. Finally, the office (e.g., Iowa's Motor Vehicle Division) that maintains the crash database can influence the activities of the other offices.

Departments of Public Safety (DPS)

Concerned, primarily, with both enforcement and general public safety. Enforcement efforts are often targeted at speed reduction, seat belt enforcement, and operating while intoxicated (OWI) elimination. Enforcement personnel are also the primary collectors of crash data, being the primary crash site responders. General public safety efforts include promotion of safety for specific populations including older drivers, young drivers, bicyclists, and pedestrians through educational programs, public service announcements (PSAs), and funding of causal factor studies. These latter efforts might be directed by a Governor's Traffic Safety Bureau (GTSB), or its equivalent.

Departments of Public Health (DPH)

With regard to transportation safety, state health departments efforts are centered around with quick and effective response to traffic crashes. Shorter response times from ambulance, fire, and enforcement are critical to improving survival of persons involved in serious traffic crashes and minimizing impacts to other motorists. State health departments are often the primary maintainers of statewide traffic crash injury details, from the health community perspective. Merging these records with traffic crash data is of great interest to many safety professionals.

Figure E.2. State government traffic safety-related agencies

Local government traffic safety-related agencies, shown in Figure E.3., are more intimately involved in the maintenance and improvement of transportation network safety. These are the agencies most likely to interact with the public and, in many cases, those impacted by traffic crashes. Each agency has a responsibility to provide the best service possible in order to protect lives and livelihood of transportation network users.

County Engineering

Maintain and improve secondary road networks. Safety concerns of county engineering would involve, primarily, rural concerns such as high speeds, animals, unforgiving shoulders, horizontal curves, inclement weather, and nighttime crashes.

City Engineering

Maintain and improve municipal road networks. Within cities, safety concerns would more likely involve intersections, business access density, pedestrians and bicyclists, and traffic control.

County Sheriffs

Enforce state and county laws including traffic laws on the secondary road network. Traffic laws are not necessarily their primary concern. Regarding traffic safety, though high speed vehicles are of concern, given the low traffic volumes this behavior is less destructive except in certain locations (e.g., sharp horizontal curves, intersections, on the fringe of urban areas). They respond to traffic crashes on the secondary road network, collecting crash information for those crashes meeting minimum reporting requirements.

City Police Departments

Enforce state and city laws including traffic laws on the municipal road network. Police departments are expected to respond to crime incidents, ensure public safety, issue citations to traffic offenders, and respond to traffic crashes. They respond to traffic crashes on the municipal road network, collecting crash information for those crashes meeting minimum reporting requirements.

Regional Planning Affiliations (RPAs)

Provide a forum for regional cooperation for the planning and coordination of roadway networks. They attempt to address many rural and urban concerns related to traffic safety across city and county boundaries.

Metropolitan Planning Organizations (MPOs)

Provide a forum for urban region cooperation for the planning and coordition of roadway networks. They attempt to address many urban concerns related to traffic safety across urban boundaries.

Fire and Rescue

Respond to emergencies requiring expertise in fire and rescue including severe traffic crashes. Many fire and rescue services are volunteer, with limited funding and equipment.

Emergency Medical Providers

Respond to medical emergencies including severe traffic crashes. Usually fairly centralized, emergency medical providers are often challenged to provide timely response to distant emergencies.

Figure E.3. Local Government traffic safety-related agencies

Figure E.4. lists a variety of professional advocacy groups. The groups shown are only a subset of all groups that are involved. Each of these groups has a responsibility to improve the practices of its members or to advocate transportation network safety.

Engineering

- American Association of State Highway and Transportation Officials (AASHTO)
- Society of Automotive Engineers (SAE)
- Institute of Transportation Engineers (ITE)
- American Society of Civil Engineers (ASCE)
- National Safety Council (NSC)
- Association of Traffic Safety Information Professionals (ATSIP)

Transit Associations

- United Motorcoach Association (UMA)
- American Bus Association (ABA)
- American Public Transportation Association (APTA)

Automobile Associations

- American Automobile Association (AAA)
- Advocates for Highway and Auto Safety

Trucking Associations

- Commercial Vehicle Safety Alliance (CVSA)
- American Trucking Association (ATA)
- National Private Truck Council (NPTC)
- Owner-Operator Independent Drivers Association (OOIDA)
- United Highway Carriers Associations (UHCA)
- National Motor Truck Association
- Truckload Carriers Association
- Highway Angels

Insurance Assocations

- Insurance Institute for Highway Safety (IIHS)
- Highway Loss Data Institute (HLDI)
- Insurance Information Institute (III)
- National Council on Compensation Insurance

Figure E.4. Professional advocacy groups

Shown in Figure E.5. is a list of citizen advocacy groups. Some groups advocate responses to particular problems (e.g., drunk driving, red light running, aggressive driving), others exist to inform members or promote traffic safety. The groups can prove valuable contributors to improvement of the transportation network.

- Sandy Johnson Foundation
- American Association of Retired People (AARP)
- Advocates for Highway and Auto Safety
- The National Campaign to Stop Red Light Running
- Citizens Against Speeding and Aggressive Driving (CASAD)
- Citizens for Reliable and Safe Highways (CRASH)
- Mothers Against Drunk Driving (MADD)
- Network of Employers for Traffic Safety (NETS)
- Parents Against Tired Truckers
- Record Artists, Actors, & Athletes Against Drunk Driving (RADD)
- Students Against Destructive Decisions (SADD)
- Underride Network

Figure E.5. Citizen advocacy groups

APPENDIX F. DATA COLLECTION FORMATS

Table F.1 displays the original site visit collection definitions.

Table F.1. Site visit data definitions

Data Field	Element Definition
Intersection Identifier	An eight-digit number denoting the intersection for crash records retrieval purposes. (digits 1 & 2 (with leading zero) = county, digits 3 & 4 = congressional township, digits 5 - 8 = unique node number within township) [1974 TRB]
North-South Road	The designation of the highest classified leg for the North-South direction.
East-West Road	The designation of the highest classified leg for the East-West direction.
Travel Direction	The direction of travel coming into the intersection for each leg, later aggregated. • N = Northbound • E = Eastbound • S = Southbound • W = Westbound Roads that were skewed from these four cardinal directions were assigned to one of them based on overall orientation of the intersection and travel direction of the extended route. These values, along with trafficway type, number of lanes, left turn lanes, right turn lanes, and traffic flow, were used to create an aggregate value depicting the geometry.
Intersection Class	The roadway classification for each leg of the intersection, later aggregated. • 1 = US highway • 2 = State highway • 3 = Municipal roadway • 4 = Interstate The values were aggregated to depict an overall intersection class.
Trafficway Type	The trafficway type for each leg of the intersection, later aggregated. • 1 = one-lane • 2 = two-lane • 3 = three-lane • 4 = 4+, undivided • 5 = 4+, divided These values, along with travel direction, number of lanes, left turn lanes, right turn lanes, and traffic flow, were used to create an aggregate value depicting the geometry of the intersection.
Number of Lanes	The number of lanes for each leg of an intersection. These values, along with travel direction, trafficway type, left turn lanes, right turn lanes, and traffic flow, were used to create an aggregate value depicting the geometry.
Lane Widths	The lane widths for each leg of an intersection. Not collected.
Left Turn Lanes	The number of left turn lanes for each leg of an intersection. These values, along with travel direction, trafficway type, number of lanes, right turn lanes, and traffic flow, were used to create an aggregate value depicting the geometry.
Right Turn Lanes	The number of right turn lanes for each leg of an intersection. These values, along with travel direction, trafficway type, number of lanes, left turn lanes, and traffic flow, were used to create an aggregate value depicting the geometry.
Speed Limit	The speed limit along each leg of an intersection (in mph).

Table F.1. (continued)

Data Field	Element Definition
Control Type	The type of traffic control device for each leg of an intersection, later aggregated. • 0 = None • 1 = Signal • 2 = Stop • 3 = Yield These data, for each intersection, were aggregated into an overall signal type for the intersection and then, with control directions, into a single variable representing control type and direction.
Topography	The vertical alignment of the approach of a leg to the intersection, later aggregated. • 1 = level • 2 = up • 3 = down • 4 = hill These data were later aggregate into a variable indicated whether the intersection was level or not. The collection of the data involved a subjective determination of whether a slight grade would adversely impact operation of the intersection.
Land Use	Indicates the adjacent land-use to the intersection for each leg of the intersection, later aggregated. • 1 = residential • 2 = business • 3 = school • 4 = manufacturing • 5 = recreational • 6 = hospital • 7 = rural • 8 = church • 9 = cemetery • 10 = parking lot These data were collected by subjectively considering what might be the land-use of "most concern" for a particular intersection leg. The land-use used as a base was residential. The data were later aggregated into an overall intersection Land Use value, again considering the land-use of most concern.
Surface Type	The type of pavement for each leg of the intersection, later aggregated. • 1 = ACC • 2 = PCC • 3 = Brick • 4 = Gravel These data were later aggregated to indicate an intersection-wide surface type.
Traffic Flow	The type of traffic flow for each leg of an intersection, later aggregated. • 1 = 1-way • 2 = 2-way These values, along with travel direction, trafficway type, number of lanes, left turn lanes, and right turn lanes, were used to create an aggregate value depicting the geometry of the intersection.
Annual Average Daily Traffic (AADT)	The volume of traffic on each leg of an intersection, as determined from the 1998 (1999 snapshot) GIMS database.

Table F.2 contains the translations that were used to convert the site visit data to intersection-wide data.

Table F.2. Site visit to intersection-wide data translations

Data Field	Data Translation Logic
Travel Direction	• If 4 legs, then Travel Direction = 1, 4-way • If 3 legs, then Travel Direction = 2, 3-way • No intersections with 5 legs or more or 2 legs or less were encountered for the Ames data.
Intersection Class	• If both routes were municipal, then Intersection Class = 1, municipal/municipal • If one route was municipal and the other US, then Intersection Class = 2, US/municipal • If one route was municipal and the other Interstate, then Intersection Class = 3, Interstate/municipal • If one route was municipal and the other Iowa (state), then Intersection Class = 4, Iowa/municipal • If any combination of non-municipal roads, then Intersection Class = 5, non-municipal • No other combinations were encountered for the Ames data.
Intersection Geometry	• If Travel Direction, post-translation, = 2, Trafficway Type = 2 from each direction, Number of Lanes coming into the intersection from each direction = 1, Left and Right Turn lanes = 0 for each direction, and traffic flow = 2 for each direction, then Intersection Geometry = 1, 3-way w/ 1-lane entering from each direction • If Travel Direction, post-translation, = 2, Trafficway Type = 4 from at least one direction, Number of Lanes coming into the intersection = 2 from at least one direction, Left and Right Turn lanes may be > 0 for at least one direction, and traffic flow = 2 for each direction, then Intersection Geometry = 2, 3-way w/ multi-lanes • If Travel Direction, post-translation, = 1, Trafficway Type = 4 from at least one direction, Number of Lanes coming into the intersection = 2 from at least one direction, Left and Right Turn lanes may be > 0 for at least one direction, and traffic flow = 2 for each direction, then Intersection Geometry = 3, 4-way w/ multi-lanes • If Travel Direction, post-translation, = 1, Trafficway Type = 2 from each direction, Number of Lanes coming into the intersection from each direction = 1, Left and Right Turn lanes = 0 for each direction, and traffic flow = 2 for each direction, then Intersection Geometry = 4, 4-way w/ single-lanes • If Travel Direction, post-translation, = 2, Trafficway Type = 2 from each direction, Number of Lanes coming into the intersection from each direction = 1, Left and Right Turn lanes = 0 for each direction, and traffic flow = 1 for at least one direction, then Intersection Geometry = 5, 3-way w/ 1-lane entering from each direction and a one-way road • If Travel Direction, post-translation, = 2, Trafficway Type = 4 from at least one direction, Number of Lanes coming into the intersection = 2 from at least one direction, Left and Right Turn lanes may be > 0 for at least one direction, and traffic flow = 1 for at least one direction, then Intersection Geometry = 6, 3-way w/ multi-lanes and a one-way road • If Travel Direction, post-translation, = 1, Trafficway Type = 4 from at least one direction, Number of Lanes coming into the intersection = 2 from at least one direction, Left and Right Turn lanes may be > 0 for at least one direction, and traffic flow = 1 for at least one direction, then Intersection Geometry = 7, 4-way w/ multi-lanes and a one-way road • If Travel Direction, post-translation, = 1, Trafficway Type = 2 from each direction, Number of Lanes coming into the intersection from each direction = 1, Left and Right Turn lanes = 0 for each direction, and traffic flow = 1 for at least one direction, then Intersection Geometry = 8, 4-way w/ single-lanes and a one-way road • If the road is an offset-T, then Intersection Geometry = 9, Offset-T
Speed Limit1	• If the highest speed on the major road = 25, then Speed Limit1 = 1, 25 mph • If the highest speed on the major road = 30, then Speed Limit1 = 2, 30 mph • If the highest speed on the major road = 35, then Speed Limit1 = 3, 35 mph • If the highest speed on the major road = 40, then Speed Limit1 = 4, 40 mph • If the highest speed on the major road ³ 45, then Speed Limit1 = 5, ³ 45 mph • If the highest speed on the major road £ 20, then Speed Limit1 = 6, £ 20 mph
Speed Limit2	• If the highest speed on the minor road = 25, then Speed Limit2 = 1, 25 mph • If the highest speed on the minor road = 30, then Speed Limit2 = 2, 30 mph • If the highest speed on the minor road = 35, then Speed Limit2 = 3, 35 mph

Table F.2. (continued)

Data Field	Data Translation Logic
	• If the highest speed on the minor road = 40, then Speed Limit2 = 4, 40 mph • If the highest speed on the minor road ^{3} 45, then Speed Limit2 = 5, 45 mph • If the highest speed on the minor road £ 20, then Speed Limit2 = 6, 20 mph
Control Type	• If at least one leg has Control Type = 1, then Control Type = 1, Traffic Signal • If at least one leg has Control Type = 2, then Control Type = 2, Stop Sign • If at least one leg has Control Type = 3, then Control Type = 3, Yield Sign • If no Control Types are indicated, then Control Type = 0, No Control
Control Directions	• If Control Directions indicates only 1 control, then Control Directions = 1, 1-way • If Control Directions indicates 2 controls, then Control Directions = 2, 2-way • If Control Directions indicates 3 controls, then Control Directions = 3, 3-way • If Control Directions indicates 4 controls, then Control Directions = 4, 4-way • If Control Directions indicates no controls, then Control Directions = 0, No Control
Topography	• If Topography = 1 for all directions, then Topography = 1, Level • If Topography <> 1 for at least one direction, then Topography = 2, Grade
Land Use	• If the Land Use for all directions = 1 or 7, then Land Use = 1, Residential/Normal (base case) • If the Land Use for at least one direction = 2 or 4 and no Land Use values = 3, 5, or 6, then Land Use = 2, Business or Manufacturing • If the Land Use for at least one direction = 3 and no Land Use values = 6, then Land Use = 3, School • If the Land Use for at least one direction = 5 and no Land Use values = 3 or 6, then Land Use = 4, Recreational • If the Land Use for at least one direction = 6, then Land Use = 5, Hospital • If the Land Use for at least one direction = 8 or 9 and no values of 3, 5, 6, 10, then Land Use = 6, Church/Cemetary • If the Land Use for at least one direction = 10 and no Land Use values 3 or 6, then Land Use = 7, Parking Lot Note: Order of precedence from non-aggregated Land Use values is 6, 3, 10, 5, 8, 4, 2, 9, 7, 1 (6 is highest, 1 is lowest).
Surface Type	• If the Surface Type within the intersection = 1, then Surface Type = 1, ACC • If the Surface Type within the intersection = 2, then Surface Type = 2, PCC
Controls	• If Control Type = 0 and Control Direction = 0, then Controls = 0, No Controls • If Control Type = 1 and Control Direction = 4, then Controls = 1, 4-way Traffic Signal • If Control Type = 1 and Control Direction = 3, then Controls = 2, 3-way Traffic Signal • If Control Type = 1 and Control Direction = 1 or 2, then Controls = 3, 1- or 2- way Signal • If Control Type = 2 and Control Direction = 4, then Controls = 4, 4-way Stop • If Control Type = 2 and Control Direction = 3, then Controls = 5, 3-way Stop • If Control Type = 2 and Control Direction = 2, then Controls = 6, 2-way Stop • If Control Type = 2 and Control Direction = 1, then Controls = 7, 1-way Stop • If Control Type = 3 and Control Direction = 2, then Controls = 8, 2-way Yield • If Control Type = 3 and Control Direction = 1, then Controls = 9, 1-way Yield
Daily Entering Vehicles	Volume of vehicles entering the intersection daily.
Total Crashes (1998)	Total crashes in 1998.

APPENDIX G. ARCVIEW CODE

To complete many of the processes and calculations within this research, several sets of computer code scipts were written. The scripts include some that assist data input and acquisition, a couple which perform the statistical processes involved in this research, and some that manipulate results from the statistical analyses to produce final results.

The ArcView GIS Avenue scripts developed for this research perform two primary functions: data entry and acquisition and data manipulation. Scripts for the first function are associated with data entry dialogs and tables from which data was acquired. Scripts for the second function analyzed data in statistical process output files and consolidated it for analysis.

Data Entry Dialogs and Crash Data Acquisition.

To ease data entry, three unique data entry screens were developed within ArcView. These tools include a volume and direction input tool, an intersection site visit data input tool, and an intersection searcher tool. For operation of individual buttons on each tool, a series of scripts were written. These scripts are listed in this section, under a heading identifying each tool.

The volume and direction input tool, shown in Figure G.1, has 11 ArcView GIS Avenue scripts tied to its

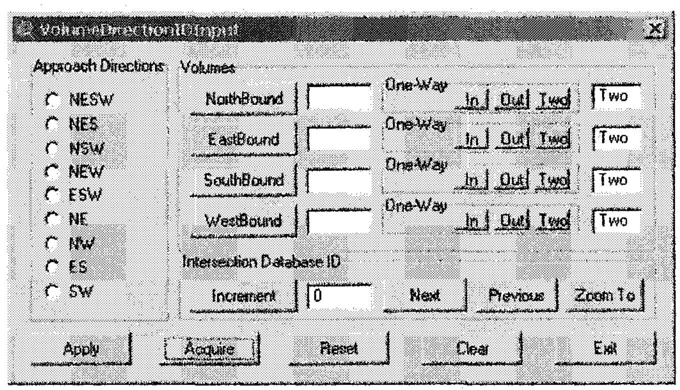


Figure G.1. Volume and direction input tool

various buttons. These scripts include:

1. _aaa.VolumeDirectionIDInput.Acquire:

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
    tFTab=t.GetFTab
  end
end

for each b in tFTab.GetSelection
  nb=tFTab.ReturnValueNumber(tFTab.FindField("NB_AADT"),b)
  eb=tFTab.ReturnValueNumber(tFTab.FindField("EB_AADT"),b)
  sb=tFTab.ReturnValueNumber(tFTab.FindField("SB_AADT"),b)
  wb=tFTab.ReturnValueNumber(tFTab.FindField("WB_AADT"),b)
  nesw=tFTab.ReturnValueString(tFTab.FindField("NESW"),b)
  intDBID=tFTab.ReturnValueNumber(tFTab.FindField("IntDB_ID"),b)
  nboneway=tFTab.ReturnValueString(tFTab.FindField("NB_OneWay"),b)
  eboneway=tFTab.ReturnValueString(tFTab.FindField("EB_OneWay"),b)
```

```
 sboneway=tFTab.ReturnValueString(tFTab.FindField("SB_OneWay"),b)
 wboneway=tFTab.ReturnValueString(tFTab.FindField("WB_OneWay"),b)
end

volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

if (volumedirectionidinputDialog.FindByName("SW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("SW").Select
elseif (volumedirectionidinputDialog.FindByName("ES").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("ES").Select
elseif (volumedirectionidinputDialog.FindByName("NW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NW").Select
elseif (volumedirectionidinputDialog.FindByName("NE").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NE").Select
elseif (volumedirectionidinputDialog.FindByName("ESW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("ESW").Select
elseif (volumedirectionidinputDialog.FindByName("NEW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NEW").Select
elseif (volumedirectionidinputDialog.FindByName("NSW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NSW").Select
elseif (volumedirectionidinputDialog.FindByName("NES").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NES").Select
elseif (volumedirectionidinputDialog.FindByName("NESW").GetName.Contains(nesw)) then
 volumedirectionidinputDialog.FindByName("NESW").Select
end

volumedirectionidinputDialog.FindByName("NB").SetText(nb.AsString)
volumedirectionidinputDialog.FindByName("EB").SetText(eb.AsString)
volumedirectionidinputDialog.FindByName("SB").SetText(sb.AsString)
volumedirectionidinputDialog.FindByName("WB").SetText(wb.AsString)

volumedirectionidinputDialog.FindByName("IntDBID").SetText(intDBID.AsString)

volumedirectionidinputDialog.FindByName("NBOneWay").SetText(nboneway.AsString)
volumedirectionidinputDialog.FindByName("EBOneWay").SetText(eboneway.AsString)
volumedirectionidinputDialog.FindByName("SBOneWay").SetText(sboneway.AsString)
volumedirectionidinputDialog.FindByName("WBOneWay").SetText(wboneway.AsString)
```

2. _aaa.VolumeDirectionIDInput.Apply

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
  tFTab=t.GetFTab
 end
end

volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

if (volumedirectionidinputDialog.FindByName("NESW").IsSelected) then
 nesw="NESW"
elseif (volumedirectionidinputDialog.FindByName("NES").IsSelected) then
 nesw="NES"
 volumedirectionidinputDialog.FindByName("WBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("NSW").IsSelected) then
 nesw="NSW"
 volumedirectionidinputDialog.FindByName("EBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("NEW").IsSelected) then
 nesw="NEW"
 volumedirectionidinputDialog.FindByName("SBOneWay").SetText("")
```

```
elseif (volumedirectionidinputDialog.FindByName("ESW").IsSelected) then
 nesw="ESW"
 volumedirectionidinputDialog.FindByName("NBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("NE").IsSelected) then
 nesw="NE"
 volumedirectionidinputDialog.FindByName("SBOneWay").SetText("")
 volumedirectionidinputDialog.FindByName("WBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("NW").IsSelected) then
 nesw="NW"
 volumedirectionidinputDialog.FindByName("EBOneWay").SetText("")
 volumedirectionidinputDialog.FindByName("SBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("ES").IsSelected) then
 nesw="ES"
 volumedirectionidinputDialog.FindByName("NBOneWay").SetText("")
 volumedirectionidinputDialog.FindByName("WBOneWay").SetText("")
elseif (volumedirectionidinputDialog.FindByName("SW").IsSelected) then
 nesw="SW"
 volumedirectionidinputDialog.FindByName("NBOneWay").SetText("")
 volumedirectionidinputDialog.FindByName("EBOneWay").SetText("")
end

if ((volumedirectionidinputDialog.FindByName("NB").GetText="").Not) then
 nb=volumedirectionidinputDialog.FindByName("NB").GetText.AsNumber
else
 nb=0
end

if ((volumedirectionidinputDialog.FindByName("EB").GetText="").Not) then
 eb=volumedirectionidinputDialog.FindByName("EB").GetText.AsNumber
else
 eb=0
end

if ((volumedirectionidinputDialog.FindByName("SB").GetText="").Not) then
 sb=volumedirectionidinputDialog.FindByName("SB").GetText.AsNumber
else
 sb=0
end

if ((volumedirectionidinputDialog.FindByName("WB").GetText="").Not) then
 wb=volumedirectionidinputDialog.FindByName("WB").GetText.AsNumber
else
 wb=0
end

if ((volumedirectionidinputDialog.FindByName("NBOneWay").GetText="").Not) then
 nboneway=volumedirectionidinputDialog.FindByName("NBOneWay").GetText
else
 nboneway=""
end

if ((volumedirectionidinputDialog.FindByName("EBOneWay").GetText="").Not) then
 eboneway=volumedirectionidinputDialog.FindByName("EBOneWay").GetText
else
 eboneway=""
end

if ((volumedirectionidinputDialog.FindByName("SBOneWay").GetText="").Not) then
 sboneway=volumedirectionidinputDialog.FindByName("SBOneWay").GetText
else
 sboneway=""
end

if ((volumedirectionidinputDialog.FindByName("WBOneWay").GetText="").Not) then
 wboneway=volumedirectionidinputDialog.FindByName("WBOneWay").GetText
else
 wboneway=""
end
```

```
if ((volumedirectionidinputDialog.FindByName("IntDBID").GetText="").Not) then
 intDBID=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber
else
 MsgBox.Warning("Intersection Database ID Invalid!"+nl+"Please enter and re-apply!","Value Error")
 intDBID=0
end

if ((nboneway="Two") and (sboneway="Two")) then
 nbsb=(nb+sb)/2
elseif ((nboneway="Two") and (sboneway="In")) then
 nbsb=nb/2+sb
elseif ((nboneway="Two") and ((sboneway="Out") or (sboneway=""))) then
 nbsb=nb/2
elseif ((nboneway="In") and (sboneway="Two")) then
 nbsb=nb+sb/2
elseif (((nboneway="Out" or (nboneway=""))) and (sboneway="Two")) then
 nbsb=sb/2
elseif ((nboneway="In") and ((sboneway="Out") or (sboneway=""))) then
 nbsb=nb
elseif ((nboneway="Out" or (nboneway="")) and (sboneway="In")) then
 nbsb=sb
elseif ((nboneway="In") and (sboneway="In")) then
 nbsb=nb+sb
elseif ((nboneway="Out" or (nboneway="")) and ((sboneway="Out") or (sboneway=""))) then
 nbsb=0
end

if ((eboneway="Two") and (wboneway="Two")) then
 ebwb=(eb+wb)/2
elseif ((eboneway="Two") and (wboneway="In")) then
 ebwb=eb/2+wb
elseif ((eboneway="Two") and ((wboneway="Out") or (wboneway=""))) then
 ebwb=eb/2
elseif ((eboneway="In") and (wboneway="Two")) then
 ebwb=eb+wb/2
elseif (((eboneway="Out" or (eboneway=""))) and (wboneway="Two")) then
 ebwb=wb/2
elseif ((eboneway="In") and ((wboneway="Out") or (wboneway=""))) then
 ebwb=eb
elseif ((eboneway="Out" or (eboneway="")) and (wboneway="In")) then
 ebwb=wb
elseif ((eboneway="In") and (wboneway="In")) then
 ebwb=eb+wb
elseif ((eboneway="Out" or (eboneway="")) and ((wboneway="Out") or (wboneway=""))) then
 ebwb=0
end

volume=nbsb+ebwb

if (tFTab.GetNumSelRecords=1) then
 tFTab.SetEditable(true)
  for each b in tFTab.GetSelection
   tFTab.SetValueNumber(tFTab.FindField("NB_AADT"),b,nb)
   tFTab.SetValueNumber(tFTab.FindField("EB_AADT"),b,eb)
   tFTab.SetValueNumber(tFTab.FindField("SB_AADT"),b,sb)
   tFTab.SetValueNumber(tFTab.FindField("WB_AADT"),b,wb)
   tFTab.SetValueString(tFTab.FindField("NESW"),b,nesw)
   tFTab.SetValueNumber(tFTab.FindField("IntDB_ID"),b,intDBID)
   if (nesw.Contains("N")) then
    tFTab.SetValueString(tFTab.FindField("NB_OneWay"),b,nboneway)
   else
    tFTab.SetValueString(tFTab.FindField("NB_OneWay"),b,"")
   end
   if (nesw.Contains("E")) then
    tFTab.SetValueString(tFTab.FindField("EB_OneWay"),b,eboneway)
   else
    tFTab.SetValueString(tFTab.FindField("EB_OneWay"),b,"")
```

```
    end
    if (nesw.Contains("S")) then
      tFTab.SetValueString(tFTab.FindField("SB_OneWay"),b,sboneway)
    else
      tFTab.SetValueString(tFTab.FindField("SB_OneWay"),b,"")
    end
    if (nesw.Contains("W")) then
      tFTab.SetValueString(tFTab.FindField("WB_OneWay"),b,wboneway)
    else
      tFTab.SetValueString(tFTab.FindField("WB_OneWay"),b,"")
    end
    tFTab.SetValueNumber(tFTab.FindField("Volume"),b,volume)
  end
  tFTab.SetEditable(false)
elseif (tFTab.GetNumSelRecords=0) then
  MsgBox.Warning("No records selected!!!","No Records")
  exit
else
  MsgBox.Warning("Multiple records selected!!!","Multiple Records")
  exit
end

intersectiondatabaseIDValue=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1
volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
  av.Run("_aaa.VolumeDirectionIDInput.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
  MsgBox.Info("Multiple records found.","Multiple Records")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
else
  MsgBox.Info("No next record.","Next Record Not Found")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
end

av.Run("_aaa.VolumeDirectionIDInput.ZoomTo","")
```

3. _aaa.VolumeDirectionIDInput.Clear

```
volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

volumedirectionidinputDialog.FindByName("NB").SetText("")
volumedirectionidinputDialog.FindByName("EB").SetText("")
volumedirectionidinputDialog.FindByName("SB").SetText("")
volumedirectionidinputDialog.FindByName("WB").SetText("")

volumedirectionidinputDialog.FindByName("NBOneWay").SetText("Two")
volumedirectionidinputDialog.FindByName("EBOneWay").SetText("Two")
volumedirectionidinputDialog.FindByName("SBOneWay").SetText("Two")
volumedirectionidinputDialog.FindByName("WBOneWay").SetText("Two")
```

4. _aaa.VolumeDirectionIDInput.Exit

```
av.FindDialog("VolumeDirectionIDInput").Close
```

5. _aaa.VolumeDirectionIDInput.Increment

```
volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")
```

```
intersectiondatabaseIDValue=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1
volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
```

6. _aaa.VolumeDirectionIDInput.Next

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
    tFTab=t.GetFTab
  end
end

volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

intersectiondatabaseIDValue=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
  av.Run("_aaa.VolumeDirectionIDInput.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
  MsgBox.Info("Multiple records found.","Multiple Records")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
else
  MsgBox.Info("No next record.","Next Record Not Found")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
end

av.Run("_aaa.VolumeDirectionIDInput.ZoomTo","")
```

7. _aaa.VolumeDirectionIDInput.OneWay

```
volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

if (self.GetName.Contains("NB")) then
  if (self.GetName.Contains("In")) then
    volumedirectionidinputDialog.FindByName("NBOneWay").SetText("In")
  elseif (self.GetName.Contains("Out")) then
    volumedirectionidinputDialog.FindByName("NBOneWay").SetText("Out")
  elseif (self.GetName.Contains("Two")) then
    volumedirectionidinputDialog.FindByName("NBOneWay").SetText("Two")
  end
elseif (self.GetName.Contains("EB")) then
  if (self.GetName.Contains("In")) then
    volumedirectionidinputDialog.FindByName("EBOneWay").SetText("In")
  elseif (self.GetName.Contains("Out")) then
    volumedirectionidinputDialog.FindByName("EBOneWay").SetText("Out")
  elseif (self.GetName.Contains("Two")) then
    volumedirectionidinputDialog.FindByName("EBOneWay").SetText("Two")
  end
elseif (self.GetName.Contains("SB")) then
  if (self.GetName.Contains("In")) then
    volumedirectionidinputDialog.FindByName("SBOneWay").SetText("In")
```

```
  elseif (self.GetName.Contains("Out")) then
    volumedirectionidinputDialog.FindByName("SBOneWay").SetText("Out")
  elseif (self.GetName.Contains("Two")) then
    volumedirectionidinputDialog.FindByName("SBOneWay").SetText("Two")
  end
elseif (self.GetName.Contains("WB")) then
  if (self.GetName.Contains("In")) then
    volumedirectionidinputDialog.FindByName("WBOneWay").SetText("In")
  elseif (self.GetName.Contains("Out")) then
    volumedirectionidinputDialog.FindByName("WBOneWay").SetText("Out")
  elseif (self.GetName.Contains("Two")) then
    volumedirectionidinputDialog.FindByName("WBOneWay").SetText("Two")
  end
end
```

8. _aaa.VolumeDirectionIDInput.Previous

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
    tFTab=t.GetFTab
  end
end

volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

intersectiondatabaseIDValue=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue-1

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
  av.Run("_aaa.VolumeDirectionIDInput.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
  MsgBox.Info("Multiple records found.","Multiple Records")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
else
  MsgBox.Info("No next record.","Next Record Not Found")
  volumedirectionidinputDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.VolumeDirectionIDInput.Clear","")
end

av.Run("_aaa.VolumeDirectionIDInput.ZoomTo","")
```

9. _aaa.VolumeDirectionIDInput.Reset

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
```

```
  tFTab=t.GetFTab
 end
end

if (tFTab.GetNumSelRecords=1) then
 tFTab.SetEditable(true)
  for each b in tFTab.GetSelection
   tFTab.SetValueNumber(tFTab.FindField("NB_AADT"),b,0)
   tFTab.SetValueNumber(tFTab.FindField("EB_AADT"),b,0)
   tFTab.SetValueNumber(tFTab.FindField("SB_AADT"),b,0)
   tFTab.SetValueNumber(tFTab.FindField("WB_AADT"),b,0)
   tFTab.SetValueString(tFTab.FindField("NESW"),b,"")
   tFTab.SetValueNumber(tFTab.FindField("IntDB_ID"),b,0)
   tFTab.SetValueString(tFTab.FindField("NB_OneWay"),b,"")
   tFTab.SetValueString(tFTab.FindField("EB_OneWay"),b,"")
   tFTab.SetValueString(tFTab.FindField("SB_OneWay"),b,"")
   tFTab.SetValueString(tFTab.FindField("WB_OneWay"),b,"")
  end
 tFTab.SetEditable(false)
else
 MsgBox.Warning("Multiple records selected!!!","Multiple Records")
 exit
end

av.Run("_aaa.VolumeDirectionIDInput.Clear","")
```

10. _aaa.VolumeDirectionIDInput.Volumes

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Roads")) then
  tFTab=t.GetFTab
  for each b in tFTab.GetSelection
   volume=tFTab.ReturnValueNumber(tFTab.FindField("AADT"),b)
  end
 end
end

volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

if (self.GetName.Contains("NorthBound")) then
 volumedirectionidinputDialog.FindByName("NB").SetText(volume.AsString)
elseif (self.GetName.Contains("EastBound")) then
 volumedirectionidinputDialog.FindByName("EB").SetText(volume.AsString)
elseif (self.GetName.Contains("SouthBound")) then
 volumedirectionidinputDialog.FindByName("SB").SetText(volume.AsString)
elseif (self.GetName.Contains("WestBound")) then
 volumedirectionidinputDialog.FindByName("WB").SetText(volume.AsString)
end
```

11. _aaa.VolumeDirectionIDInput.ZoomTo

```
volumedirectionidinputDialog=av.FindDialog("VolumeDirectionIDInput")

intersectiondatabaseIDValue=volumedirectionidinputDialog.FindByName("IntDBID").GetText.AsNumber

theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
```

```
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
    tFTab=t.GetFTab

    tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
    tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
    tFTab.UpdateSelection

    r = Rect.MakeEmpty
    r = r.UnionWith(t.GetSelectedExtent)

    if (r.IsEmpty) then
      return nil
    elseif ( r.ReturnSize = (0@0) ) then
      theView.GetDisplay.PanTo(r.ReturnOrigin)
    else
      theView.GetDisplay.SetExtent(r.Scale(1.1))
    end
  end
end
```

The intersection site visit data input tool, shown in Figure G.2, has 10 ArcView GIS Avenue scripts

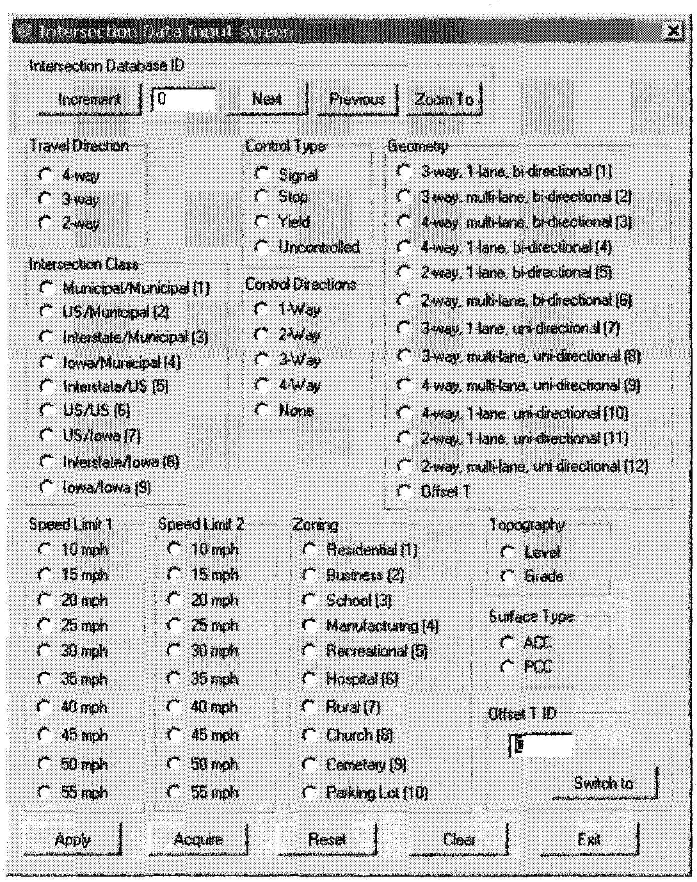


Figure G.2. Intersection site visit input dialog

associated with its various buttons. Some of the scripts are similar to scripts written for the volume and direction input tool but apply only to this tool. The scripts for the intersection site visit data input tool include:

1. _aaa.IntersectionDataInputScreen.Acquire

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
  tFTab=t.GetFTab
 end
end

for each b in tFTab.GetSelection
 traveldirection=tFTab.ReturnValueNumber(tFTab.FindField("TravelDir"),b)
 intersectionclass=tFTab.ReturnValueNumber(tFTab.FindField("IntClass"),b)
 controltype=tFTab.ReturnValueNumber(tFTab.FindField("ContType"),b)
 controldirections=tFTab.ReturnValueNumber(tFTab.FindField("ContDirs"),b)
 speedlimit1=tFTab.ReturnValueNumber(tFTab.FindField("SpeedLmt1"),b)
 speedlimit2=tFTab.ReturnValueNumber(tFTab.FindField("SpeedLmt2"),b)
 geometry=tFTab.ReturnValueNumber(tFTab.FindField("Geometry"),b)
 zoning=tFTab.ReturnValueNumber(tFTab.FindField("Zoning"),b)
 topography=tFTab.ReturnValueNumber(tFTab.FindField("Topography"),b)
 surfacetype=tFTab.ReturnValueNumber(tFTab.FindField("SurfType"),b)
 intDBID=tFTab.ReturnValueNumber(tFTab.FindField("IntDB_ID"),b)
 offsetTID=tFTab.ReturnValueNumber(tFTab.FindField("OffsetTID"),b)
end

intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intDBID.AsString)

intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").SetText(offsetTID.AsString)

if (traveldirection=1) then
 intersectiondatainputscreenDialog.FindByName("FourWayTravelDirection").Select
elseif (traveldirection=2) then
 intersectiondatainputscreenDialog.FindByName("ThreeWayTravelDirection").Select
elseif (traveldirection=3) then
 intersectiondatainputscreenDialog.FindByName("TwoWayTravelDirection").Select
else
 intersectiondatainputscreenDialog.FindByName("FourWayTravelDirection").Select
end

if (intersectionclass=1) then
 intersectiondatainputscreenDialog.FindByName("MunicipalMunicipal").Select
elseif (intersectionclass=2) then
 intersectiondatainputscreenDialog.FindByName("USMunicipal").Select
elseif (intersectionclass=3) then
 intersectiondatainputscreenDialog.FindByName("InterstateMunicipal").Select
elseif (intersectionclass=4) then
 intersectiondatainputscreenDialog.FindByName("IowaMunicipal").Select
elseif (intersectionclass=5) then
 intersectiondatainputscreenDialog.FindByName("InterstateUS").Select
elseif (intersectionclass=6) then
 intersectiondatainputscreenDialog.FindByName("USUS").Select
elseif (intersectionclass=7) then
 intersectiondatainputscreenDialog.FindByName("USIowa").Select
elseif (intersectionclass=8) then
 intersectiondatainputscreenDialog.FindByName("InterstateIowa").Select
elseif (intersectionclass=9) then
```

```
  intersectiondatainputscreenDialog.FindByName("IowaIowa").Select
else
  intersectiondatainputscreenDialog.FindByName("MunicipalMunicipal").Select
end

if (controltype=1) then
  intersectiondatainputscreenDialog.FindByName("Signal").Select
elseif (controltype=2) then
  intersectiondatainputscreenDialog.FindByName("Stop").Select
elseif (controltype=3) then
  intersectiondatainputscreenDialog.FindByName("Yield").Select
elseif (controltype=0) then
  intersectiondatainputscreenDialog.FindByName("Uncontrolled").Select
else
  intersectiondatainputscreenDialog.FindByName("Signal").Select
end

if (controldirections=1) then
  intersectiondatainputscreenDialog.FindByName("OneWayControlDirection").Select
elseif (controldirections=2) then
  intersectiondatainputscreenDialog.FindByName("TwoWayControlDirection").Select
elseif (controldirections=3) then
  intersectiondatainputscreenDialog.FindByName("ThreeWayControlDirection").Select
elseif (controldirections=4) then
  intersectiondatainputscreenDialog.FindByName("FourWayControlDirection").Select
elseif (controldirections=0) then
  intersectiondatainputscreenDialog.FindByName("NoneControlDirection").Select
else
  intersectiondatainputscreenDialog.FindByName("OneWayControlDirection").Select
end

if (geometry=1) then
  intersectiondatainputscreenDialog.FindByName("geometry01").Select
elseif (geometry=2) then
  intersectiondatainputscreenDialog.FindByName("geometry02").Select
elseif (geometry=3) then
  intersectiondatainputscreenDialog.FindByName("geometry03").Select
elseif (geometry=4) then
  intersectiondatainputscreenDialog.FindByName("geometry04").Select
elseif (geometry=5) then
  intersectiondatainputscreenDialog.FindByName("geometry05").Select
elseif (geometry=6) then
  intersectiondatainputscreenDialog.FindByName("geometry06").Select
elseif (geometry=7) then
  intersectiondatainputscreenDialog.FindByName("geometry07").Select
elseif (geometry=8) then
  intersectiondatainputscreenDialog.FindByName("geometry08").Select
elseif (geometry=9) then
  intersectiondatainputscreenDialog.FindByName("geometry09").Select
elseif (geometry=10) then
  intersectiondatainputscreenDialog.FindByName("geometry10").Select
elseif (geometry=11) then
  intersectiondatainputscreenDialog.FindByName("geometry11").Select
elseif (geometry=12) then
  intersectiondatainputscreenDialog.FindByName("geometry12").Select
elseif (geometry=13) then
  intersectiondatainputscreenDialog.FindByName("geometry13").Select
else
  intersectiondatainputscreenDialog.FindByName("geometry01").Select
end

if (speedlimit1=8) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH10").Select
elseif (speedlimit1=9) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH15").Select
elseif (speedlimit1=10) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH20").Select
elseif (speedlimit1=1) then
```

```
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH25").Select
elseif (speedlimit1=2) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH30").Select
elseif (speedlimit1=3) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH35").Select
elseif (speedlimit1=4) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH40").Select
elseif (speedlimit1=5) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH45").Select
elseif (speedlimit1=6) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH50").Select
elseif (speedlimit1=7) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH55").Select
else
  intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH10").Select
end

if (speedlimit2=8) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH10").Select
elseif (speedlimit2=9) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH15").Select
elseif (speedlimit2=10) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH20").Select
elseif (speedlimit2=1) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH25").Select
elseif (speedlimit2=2) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH30").Select
elseif (speedlimit2=3) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH35").Select
elseif (speedlimit2=4) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH40").Select
elseif (speedlimit2=5) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH45").Select
elseif (speedlimit2=6) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH50").Select
elseif (speedlimit2=7) then
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH55").Select
else
  intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH10").Select
end

if (zoning=1) then
  intersectiondatainputscreenDialog.FindByName("Residential").Select
elseif (zoning=2) then
  intersectiondatainputscreenDialog.FindByName("Business").Select
elseif (zoning=3) then
  intersectiondatainputscreenDialog.FindByName("School").Select
elseif (zoning=4) then
  intersectiondatainputscreenDialog.FindByName("Manufacturing").Select
elseif (zoning=5) then
  intersectiondatainputscreenDialog.FindByName("Recreational").Select
elseif (zoning=6) then
  intersectiondatainputscreenDialog.FindByName("Hospital").Select
elseif (zoning=7) then
  intersectiondatainputscreenDialog.FindByName("Rural").Select
elseif (zoning=8) then
  intersectiondatainputscreenDialog.FindByName("Church").Select
elseif (zoning=9) then
  intersectiondatainputscreenDialog.FindByName("Cemetary").Select
elseif (zoning=10) then
  intersectiondatainputscreenDialog.FindByName("ParkingLot").Select
else
  intersectiondatainputscreenDialog.FindByName("Residential").Select
end

if (topography=1) then
  intersectiondatainputscreenDialog.FindByName("Level").Select
elseif (topography=2) then
```

```
 intersectiondatainputscreenDialog.FindByName("Grade").Select
else
 intersectiondatainputscreenDialog.FindByName("Level").Select
end

if (surfacetype=1) then
 intersectiondatainputscreenDialog.FindByName("ACC").Select
elseif (surfacetype=2) then
 intersectiondatainputscreenDialog.FindByName("PCC").Select
else
 intersectiondatainputscreenDialog.FindByName("ACC").Select
end
```

2. _aaa.IntersectionDataInputScreen.Apply

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
  tFTab=t.GetFTab
 end
end

intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

if ((intersectiondatainputscreenDialog.FindByName("IntDBID").GetText="").Not) then
 intDBID=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber
else
 MsgBox.Warning("Intersection Database ID Invalid!"+nl+"Please enter and re-apply!","Value Error")
 intDBID=0
end

if ((intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").GetText="").Not) then
 offsetTID=intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").GetText.AsNumber
else
 MsgBox.Warning("Offset T ID Invalid!"+nl+"Please enter and re-apply!","Value Error")
 offsetTID=0
end

if (intersectiondatainputscreenDialog.FindByName("FourWayTravelDirection").IsSelected) then
 traveldirection=1
elseif (intersectiondatainputscreenDialog.FindByName("ThreeWayTravelDirection").IsSelected) then
 traveldirection=2
elseif (intersectiondatainputscreenDialog.FindByName("TwoWayTravelDirection").IsSelected) then
 traveldirection=3
end

if (intersectiondatainputscreenDialog.FindByName("MunicipalMunicipal").IsSelected) then
 intersectionclass=1
elseif (intersectiondatainputscreenDialog.FindByName("USMunicipal").IsSelected) then
 intersectionclass=2
elseif (intersectiondatainputscreenDialog.FindByName("InterstateMunicipal").IsSelected) then
 intersectionclass=3
elseif (intersectiondatainputscreenDialog.FindByName("IowaMunicipal").IsSelected) then
 intersectionclass=4
elseif (intersectiondatainputscreenDialog.FindByName("InterstateUS").IsSelected) then
 intersectionclass=5
elseif (intersectiondatainputscreenDialog.FindByName("USUS").IsSelected) then
 intersectionclass=6
elseif (intersectiondatainputscreenDialog.FindByName("USIowa").IsSelected) then
 intersectionclass=7
```

```
elseif (intersectiondatainputscreenDialog.FindByName("InterstateIowa").IsSelected) then
 intersectionclass=8
elseif (intersectiondatainputscreenDialog.FindByName("IowaIowa").IsSelected) then
 intersectionclass=9
end

if (intersectiondatainputscreenDialog.FindByName("Signal").IsSelected) then
 controltype=1
elseif (intersectiondatainputscreenDialog.FindByName("Stop").IsSelected) then
 controltype=2
elseif (intersectiondatainputscreenDialog.FindByName("Yield").IsSelected) then
 controltype=3
elseif (intersectiondatainputscreenDialog.FindByName("Uncontrolled").IsSelected) then
 controltype=0
end

if (intersectiondatainputscreenDialog.FindByName("OneWayControlDirection").IsSelected) then
 controldirections=1
elseif (intersectiondatainputscreenDialog.FindByName("TwoWayControlDirection").IsSelected) then
 controldirections=2
elseif (intersectiondatainputscreenDialog.FindByName("ThreeWayControlDirection").IsSelected) then
 controldirections=3
elseif (intersectiondatainputscreenDialog.FindByName("FourWayControlDirection").IsSelected) then
 controldirections=4
elseif (intersectiondatainputscreenDialog.FindByName("NoneControlDirection").IsSelected) then
 controldirections=0
end

if (intersectiondatainputscreenDialog.FindByName("geometry01").IsSelected) then
 geometry=1
elseif (intersectiondatainputscreenDialog.FindByName("geometry02").IsSelected) then
 geometry=2
elseif (intersectiondatainputscreenDialog.FindByName("geometry03").IsSelected) then
 geometry=3
elseif (intersectiondatainputscreenDialog.FindByName("geometry04").IsSelected) then
 geometry=4
elseif (intersectiondatainputscreenDialog.FindByName("geometry05").IsSelected) then
 geometry=5
elseif (intersectiondatainputscreenDialog.FindByName("geometry06").IsSelected) then
 geometry=6
elseif (intersectiondatainputscreenDialog.FindByName("geometry07").IsSelected) then
 geometry=7
elseif (intersectiondatainputscreenDialog.FindByName("geometry08").IsSelected) then
 geometry=8
elseif (intersectiondatainputscreenDialog.FindByName("geometry09").IsSelected) then
 geometry=9
elseif (intersectiondatainputscreenDialog.FindByName("geometry10").IsSelected) then
 geometry=10
elseif (intersectiondatainputscreenDialog.FindByName("geometry11").IsSelected) then
 geometry=11
elseif (intersectiondatainputscreenDialog.FindByName("geometry12").IsSelected) then
 geometry=12
elseif (intersectiondatainputscreenDialog.FindByName("geometry13").IsSelected) then
 geometry=13
end

if (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH10").IsSelected) then
 speedlimit1=8
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH15").IsSelected) then
 speedlimit1=9
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH20").IsSelected) then
 speedlimit1=10
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH25").IsSelected) then
 speedlimit1=1
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH30").IsSelected) then
 speedlimit1=2
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH35").IsSelected) then
 speedlimit1=3
```

```
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH40").IsSelected) then
 speedlimit1=4
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH45").IsSelected) then
 speedlimit1=5
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH50").IsSelected) then
 speedlimit1=6
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH55").IsSelected) then
 speedlimit1=7
end

if (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH10").IsSelected) then
 speedlimit2=8
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH15").IsSelected) then
 speedlimit2=9
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH20").IsSelected) then
 speedlimit2=10
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH25").IsSelected) then
 speedlimit2=1
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH30").IsSelected) then
 speedlimit2=2
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH35").IsSelected) then
 speedlimit2=3
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH40").IsSelected) then
 speedlimit2=4
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH45").IsSelected) then
 speedlimit2=5
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH50").IsSelected) then
 speedlimit2=6
elseif (intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH55").IsSelected) then
 speedlimit2=7
end

if (intersectiondatainputscreenDialog.FindByName("Residential").IsSelected) then
 zoning=1
elseif (intersectiondatainputscreenDialog.FindByName("Business").IsSelected) then
 zoning=2
elseif (intersectiondatainputscreenDialog.FindByName("School").IsSelected) then
 zoning=3
elseif (intersectiondatainputscreenDialog.FindByName("Manufacturing").IsSelected) then
 zoning=4
elseif (intersectiondatainputscreenDialog.FindByName("Recreational").IsSelected) then
 zoning=5
elseif (intersectiondatainputscreenDialog.FindByName("Hospital").IsSelected) then
 zoning=6
elseif (intersectiondatainputscreenDialog.FindByName("Rural").IsSelected) then
 zoning=7
elseif (intersectiondatainputscreenDialog.FindByName("Church").IsSelected) then
 zoning=8
elseif (intersectiondatainputscreenDialog.FindByName("Cemetary").IsSelected) then
 zoning=9
elseif (intersectiondatainputscreenDialog.FindByName("ParkingLot").IsSelected) then
 zoning=10
end

if (intersectiondatainputscreenDialog.FindByName("Level").IsSelected) then
 topography=1
elseif (intersectiondatainputscreenDialog.FindByName("Grade").IsSelected) then
 topography=2
end

if (intersectiondatainputscreenDialog.FindByName("ACC").IsSelected) then
 surfacetype=1
elseif (intersectiondatainputscreenDialog.FindByName("PCC").IsSelected) then
 surfacetype=2
end

if (tFTab.GetNumSelRecords=1) then
 tFTab.SetEditable(true)
```

```
  for each b in tFTab.GetSelection
   tFTab.SetValueNumber(tFTab.FindField("TravelDir"),b,traveldirection)
   tFTab.SetValueNumber(tFTab.FindField("IntClass"),b,intersectionclass)
   tFTab.SetValueNumber(tFTab.FindField("ContType"),b,controltype)
   tFTab.SetValueNumber(tFTab.FindField("ContDirs"),b,controldirections)
   tFTab.SetValueNumber(tFTab.FindField("SpeedLmt1"),b,speedlimit1)
   tFTab.SetValueNumber(tFTab.FindField("SpeedLmt2"),b,speedlimit2)
   tFTab.SetValueNumber(tFTab.FindField("Geometry"),b,geometry)
   tFTab.SetValueNumber(tFTab.FindField("Zoning"),b,zoning)
   tFTab.SetValueNumber(tFTab.FindField("Topography"),b,topography)
   tFTab.SetValueNumber(tFTab.FindField("SurfType"),b,surfacetype)
   tFTab.SetValueNumber(tFTab.FindField("OffsetTID"),b,offsetTID)
  end
 tFTab.SetEditable(false)
elseif (tFTab.GetNumSelRecords=0) then
 MsgBox.Warning("No records selected!!!","No Records")
 exit
else
 MsgBox.Warning("Multiple records selected!!!","Multiple Records")
 exit
end

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1
intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
 av.Run("_aaa.IntersectionDataInputScreen.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
 MsgBox.Info("Multiple records found.","Multiple Records")
 intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
 av.Run("_aaa.IntersectionDataInputScreen.Clear","")
else
 MsgBox.Info("No next record.","Next Record Not Found")
 intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
 av.Run("_aaa.IntersectionDataInputScreen.Clear","")
end

av.Run("_aaa.IntersectionDataInputScreen.ZoomTo","")
```

3. _aaa.IntersectionDataInputScreen.Clear

```
intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatainputscreenDialog.FindByName("FourWayTravelDirection").Select
intersectiondatainputscreenDialog.FindByName("MunicipalMunicipal").Select
intersectiondatainputscreenDialog.FindByName("Signal").Select
intersectiondatainputscreenDialog.FindByName("OneWayControlDirection").Select
intersectiondatainputscreenDialog.FindByName("geometry01").Select
intersectiondatainputscreenDialog.FindByName("SpeedLimit1MPH10").Select
intersectiondatainputscreenDialog.FindByName("SpeedLimit2MPH10").Select
intersectiondatainputscreenDialog.FindByName("Residential").Select
intersectiondatainputscreenDialog.FindByName("Level").Select
intersectiondatainputscreenDialog.FindByName("ACC").Select
intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").SetText("0")
```

4. _aaa.IntersectionDataInputScreen.Exit

```
av.FindDialog("IntersectionDataInputScreen").Close
```

5. _aaa.IntersectionDataInputScreen.Increment

```
intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1
intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
```

6. _aaa.IntersectionDataInputScreen.Next

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
  tFTab=t.GetFTab
 end
end

intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue+1

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
 av.Run("_aaa.IntersectionDataInputScreen.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
 MsgBox.Info("Multiple records found.","Multiple Records")
 intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
 av.Run("_aaa.IntersectionDataInputScreen.Clear","")
else
 MsgBox.Info("No next record.","Next Record Not Found")
 intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
 av.Run("_aaa.IntersectionDataInputScreen.Clear","")
end

av.Run("_aaa.IntersectionDataInputScreen.ZoomTo","")
```

7. _aaa.IntersectionDataInputScreen.Previous

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
  tFTab=t.GetFTab
 end
end

intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber
intersectiondatabaseIDValue=intersectiondatabaseIDValue-1
```

```
tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
  av.Run("_aaa.IntersectionDataInputScreen.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
  MsgBox.Info("Multiple records found.","Multiple Records")
  intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.IntersectionDataInputScreen.Clear","")
else
  MsgBox.Info("No next record.","Next Record Not Found")
  intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.IntersectionDataInputScreen.Clear","")
end

av.Run("_aaa.IntersectionDataInputScreen.ZoomTo","")
```

8. _aaa.IntersectionDataInputScreen.Reset

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
    tFTab=t.GetFTab
  end
end

if (tFTab.GetNumSelRecords=1) then
  tFTab.SetEditable(true)
   for each b in tFTab.GetSelection
    tFTab.SetValueNumber(tFTab.FindField("TravelDir"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("IntClass"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("ContType"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("ContDirs"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("SpeedLmt1"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("SpeedLmt2"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("Geometry"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("Zoning"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("Topography"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("SurfType"),b,0)
    tFTab.SetValueNumber(tFTab.FindField("OffsetTID"),b,0)
   end
  tFTab.SetEditable(false)
elseif (tFTab.GetNumSelRecords=0) then
  MsgBox.Warning("No records selected!!!","No Records")
  exit
else
  MsgBox.Warning("Multiple records selected!!!","Multiple Records")
  exit
end

av.Run("_aaa.IntersectionDataInputScreen.Clear","")
```

9. _aaa.IntersectionDataInputScreen.SwitchTo

```
theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
```

```
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
    tFTab=t.GetFTab
  end
end

intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

if ((intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").GetText="").Not) then
  offsetTID=intersectiondatainputscreenDialog.FindByName("OffsetTIDBox").GetText.AsNumber
else
  MsgBox.Warning("Offset T ID Invalid!"+nl+"Please enter and re-apply!","Value Error")
  offsetTID=0
  exit
end

if (offsetTID=0) then
  MsgBox.Warning("No Offset T ID specified!","Invalid Offset T ID")
  exit
end

intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(offsetTID.AsString)

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber

tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

if (tFTab.GetNumSelRecords=1) then
  av.Run("_aaa.IntersectionDataInputScreen.Acquire","")
elseif (tFTab.GetNumSelRecords>1) then
  MsgBox.Info("Multiple records found.","Multiple Records")
  intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.IntersectionDataInputScreen.Clear","")
else
  MsgBox.Info("No next record.","Next Record Not Found")
  intersectiondatainputscreenDialog.FindByName("IntDBID").SetText(intersectiondatabaseIDValue.AsString)
  av.Run("_aaa.IntersectionDataInputScreen.Clear","")
end

av.Run("_aaa.IntersectionDataInputScreen.ZoomTo","")
```

10. _aaa.IntersectionDataInputScreen.ZoomTo

```
intersectiondatainputscreenDialog=av.FindDialog("IntersectionDataInputScreen")

intersectiondatabaseIDValue=intersectiondatainputscreenDialog.FindByName("IntDBID").GetText.AsNumber

theDocList=av.GetProject.GetDocs
for each d in theDocList
  if (d.Is(View)) then
    theView=d
  end
end

theThemesList=theView.GetThemes
for each t in theThemesList
  if (t.GetName.Contains("Desmoines_nodes_05112003join.shp")) then
    tFTab=t.GetFTab

    tExpr="([IntDB_ID] ="++intersectiondatabaseIDValue.AsString++")"
    tFTab.Query(tExpr,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
```

```
  tFTab.UpdateSelection

  r = Rect.MakeEmpty
  r = r.UnionWith(t.GetSelectedExtent)

  if (r.IsEmpty) then
   return nil
  elseif ( r.ReturnSize = (0@0) ) then
   theView.GetDisplay.PanTo(r.ReturnOrigin)
  else
   theView.GetDisplay.SetExtent(r.Scale(1.1))
  end
 end
end
```

The intersection site visit data input tool, shown in Figure G.3, has 3 ArcView GIS Avenue scripts associated

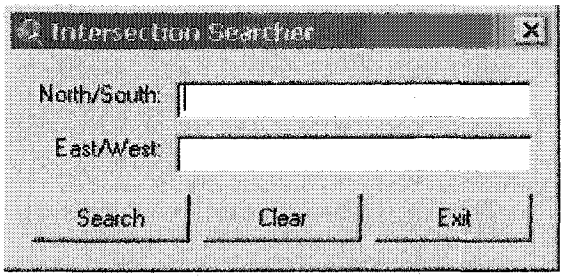


Figure G.3. Intersection searcher dialog

with its various buttons. The scripts for the intersection site visit data input tool include:

1. _aaa.IntersectionSearcher.Search

```
intersectionsearcher=av.FindDialog("IntersectionSearcher")

northsouth=intersectionsearcher.FindByName("NorthSouth")
 northsouthText=northsouth.GetText

eastwest=intersectionsearcher.FindByName("EastWest")
 eastwestText=eastwest.GetText

'*********************************************************
'*** Switch this to finding the theme and then the FTab ***
'*********************************************************

theDocList=av.GetProject.GetDocs
for each d in theDocList
 if (d.Is(View)) then
  theView=d
 end
end

theThemesList=theView.GetThemes
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
  tFTab=t.GetFTab
 end
end

if ((northsouthText.Count>0) and (eastwestText.Count>0)) then
 nodesQueryText="(([Northsouth].Contains("+northsouthText.Quote+")) and ([Eastwest].Contains("+eastwestText.Quote+")))"
elseif (northsouthText.Count>0) then
 nodesQueryText="([Northsouth].Contains("+northsouthText.Quote+"))"
elseif (eastwestText.Count>0) then
```

```
 nodesQueryText="([Eastwest].Contains("+eastwestText.Quote+"))"
else
 MsgBox.Error("You must enter either a North/South or an East/West!!!","Entry Error")
 exit
end
tFTab.Query(nodesQueryText,tFTab.GetSelection,#VTAB_SELTYPE_NEW)
tFTab.UpdateSelection

tFTab.UpdateSelection

r = Rect.MakeEmpty
for each t in theThemesList
 if (t.GetName.Contains("Desmoines_nodes_03262003join.shp")) then
  r = r.UnionWith(t.GetSelectedExtent)
 end
end
if (r.IsEmpty) then
 return nil
elseif ( r.ReturnSize = (0@0) ) then
 theView.GetDisplay.PanTo(r.ReturnOrigin)
else
 theView.GetDisplay.SetExtent(r.Scale(1.1))
end
```

2. _aaa.IntersectionSearcher.Clear

```
intersectionsearcher=av.FindDialog("IntersectionSearcher")

northsouth=intersectionsearcher.FindByName("NorthSouth")
 northsouth.SetText("")

eastwest=intersectionsearcher.FindByName("EastWest")
 eastwest.SetText("")
```

3. _aaa.IntersectionSearcher.Exit

```
intersectionsearcher=av.FindDialog("IntersectionSearcher")
intersectionsearcher.Close
```

Additionally, an ArcView GIS Avenue script was written for Crash Data Acquisition.

```
intersectionTable=av.FindDoc("intersectionidentifiesandnodes.dbf")
 intersectionVTab=intersectionTable.GetVTab

sYear=1991
while (sYear<=2000)

 intersectionVTab.SetEditable(true)

 aTable=av.FindDoc("za"+sYear.AsString+".dbf")
  aVTab=aTable.GetVTab

 aVTab.CreateIndex(aVTab.FindField("County"))
 aVTab.CreateIndex(aVTab.FindField("Int_ID"))

 for each r in intersectionVTab
  id=intersectionVTab.ReturnValueString(intersectionVTab.FindField("ID"),r)
  if (id.Count=7) then
   county=id.Left(1)
  else
   county=id.Left(2)
  end
  townshipnode=id.Right(6)

  aExpr="([County] ="++county++") and ([Int_ID] ="++townshipnode++")"
  aVTab.Query(aExpr,aVTab.GetSelection,#VTAB_SELTYPE_NEW)
```

```
    if (aVTab.GetNumSelRecords>0) then

      totalCrashes=aVTab.GetNumSelRecords

       intersectionVTab.SetValue(intersectionVTab.FindField("C"+sYear.AsString),r,totalCrashes)
    else
       intersectionVTab.SetValue(intersectionVTab.FindField("C"+sYear.AsString),r,0)
    end
  end

  intersectionVTab.SetEditable(false)
  sYear=sYear+1
end
```

Bayesian Analysis Result Final Generation.

Data results from the BUGS data runs require further manipulation to produce meaningful results in terms of crash frequency and crash rate. The output from BUGS provides draws of each individual β related to each covariate. To obtain crash frequency and rate, these βs must be multiplied to the covariates for each site for each β draw. This produces draws of frequency and rate equal to the number of β draws, which can then examined further.

Frequency and rate means were calculated using the following scripts. The scripts calculate means, maximums, minimums, variances, standard deviations, etc. for each site. The individual scripts are:

1. Frequency Means:

```
theFrequencyTableList=List.Make
 theFrequencyTableList.Add("data_lambda_2500x1_250_07312003.dbf")
 theFrequencyTableList.Add("data_lambda_2500x251_500_07312003.dbf")
 theFrequencyTableList.Add("data_lambda_2500x501_750_07312003.dbf")
 theFrequencyTableList.Add("data_lambda_2500x751_1000_07312003.dbf")
 theFrequencyTableList.Add("data_lambda_2500x1001_1031_07312003.dbf")

theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\frequencymeans").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 intField=Field.Make("IntNum",#FIELD_SHORT,4,0)
  nFieldsList.Add(intField)
 countField=Field.Make("Count",#FIELD_SHORT,4,0)
  nFieldsList.Add(countField)
 meanField=Field.Make("Mean",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(meanField)
 maxField=Field.Make("Maximum",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(maxField)
 minField=Field.Make("Minimum",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(minField)
 rangeField=Field.Make("Range",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(rangeField)
 varField=Field.Make("Variance",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(varField)
 stdField=Field.Make("StanDev",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(stdField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

fCount=1
for each t in theFrequencyTableList

  theTable=av.FindDoc(t)
  theVTab = theTable.GetVTab
```

```
theVTabFieldsList=theVTab.GetFields

for each f in theVTabFieldsList
 if ((f.GetName="Draw").Not) then
  theField = f

  thePrecision = "d.ddddddddd"
  theFieldPrecision = theField.GetPrecision
  Script.The.SetNumberFormat( thePrecision.Left( theFieldPrecision + 2 ) )

  if ( theVTab.GetSelection.Count = 0 ) then
   theSet = theVTab
  else
   theSet = theVTab.GetSelection
  end

  theSum = 0
  theCount = 0
  theMinimum = nil
  theMaximum = nil
  for each rec in theSet
   theValue = theVTab.ReturnValueNumber( theField, rec )
   if ( not ( theValue.IsNull ) ) then
    if ( theMinimum = nil ) then
     theMinimum = theValue
     theMaximum = theValue
    else
     theMinimum = theMinimum min theValue
     theMaximum = theMaximum max theValue
    end
    theSum = theValue + theSum
    theCount = theCount + 1
   end
  end
  theMean = theSum / theCount

  theSumSqDev = 0
  for each rec in theSet
   theValue = theVTab.ReturnValueNumber( theField, rec )
   if ( not ( theValue.IsNull ) ) then
    theSqDev = ( theValue - theMean ) * ( theValue - theMean )
    theSumSqDev = theSqDev + theSumSqDev
   end
  end

  if (theCount > 1) then
   theVariance = theSumsqdev / (theCount - 1)
   theStdDev = theVariance.Sqrt
  else
   theVariance = 0
   theStdDev = 0
  end

  nVTab.SetEditable(true)
   nRow=nVTab.AddRecord
   nVTab.SetValue(nVTab.FindField("IntNum"),nRow,fCount)
   nVTab.SetValue(nVTab.FindField("Count"),nRow,theCount)
   nVTab.SetValue(nVTab.FindField("Mean"),nRow,theMean)
   nVTab.SetValue(nVTab.FindField("Maximum"),nRow,theMaximum)
   nVTab.SetValue(nVTab.FindField("Minimum"),nRow,theMinimum)
   nVTab.SetValue(nVTab.FindField("Range"),nRow,(theMaximum-theMinimum).Abs)
   nVTab.SetValue(nVTab.FindField("Variance"),nRow,theVariance)
   nVTab.SetValue(nVTab.FindField("StanDev"),nRow,theStdDev)
  nVTab.SetEditable(false)

  fCount=fCount+1
 end
end
```

```
end
```

2. Rate Means:

```
nTable=Table.Make(nVTab)
nTable.GetWin.Open
nTable.SetName("Frequency Means")

theVolumeTableList=List.Make
 theVolumeTableList.Add("data_lambdavolume_2500x1_250_07312003.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x251_500_07312003.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x501_750_07312003.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x751_1000_07312003.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x1001_1031_07312003.dbf")

theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\ratemeans").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 intField=Field.Make("IntNum",#FIELD_SHORT,4,0)
  nFieldsList.Add(intField)
 countField=Field.Make("Count",#FIELD_SHORT,4,0)
  nFieldsList.Add(countField)
 meanField=Field.Make("Mean",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(meanField)
 maxField=Field.Make("Maximum",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(maxField)
 minField=Field.Make("Minimum",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(minField)
 rangeField=Field.Make("Range",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(rangeField)
 varField=Field.Make("Variance",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(varField)
 stdField=Field.Make("StanDev",#FIELD_DOUBLE,8,4)
  nFieldsList.Add(stdField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

fCount=1
for each t in theVolumeTableList

  theTable=av.FindDoc(t)
  theVTab = theTable.GetVTab
  theVTabFieldsList=theVTab.GetFields

  for each f in theVTabFieldsList
   if ((f.GetName="Draw").Not) then
    theField = f

    thePrecision = "d.dddddddddd"
    theFieldPrecision = theField.GetPrecision
    Script.The.SetNumberFormat( thePrecision.Left( theFieldPrecision + 2 ) )

    if ( theVTab.GetSelection.Count = 0 ) then
     theSet = theVTab
    else
     theSet = theVTab.GetSelection
    end

    theSum = 0
    theCount = 0
    theMinimum = nil
    theMaximum = nil
    for each rec in theSet
```

```
  theValue = theVTab.ReturnValueNumber( theField, rec )
  if ( not ( theValue.IsNull ) ) then
   if ( theMinimum = nil ) then
    theMinimum = theValue
    theMaximum = theValue
   else
    theMinimum = theMinimum min theValue
    theMaximum = theMaximum max theValue
   end
   theSum = theValue + theSum
   theCount = theCount + 1
  end
 end
 theMean = theSum / theCount

 theSumSqDev = 0
 for each rec in theSet
  theValue = theVTab.ReturnValueNumber( theField, rec )
  if ( not ( theValue.IsNull ) ) then
   theSqDev = ( theValue - theMean ) * ( theValue - theMean )
   theSumSqDev = theSqDev + theSumSqDev
  end
 end

 if (theCount > 1) then
  theVariance = theSumsqdev / (theCount - 1)
  theStdDev = theVariance.Sqrt
 else
  theVariance = 0
  theStdDev = 0
 end

 nVTab.SetEditable(true)
  nRow=nVTab.AddRecord
  nVTab.SetValue(nVTab.FindField("IntNum"),nRow,fCount)
  nVTab.SetValue(nVTab.FindField("Count"),nRow,theCount)
  nVTab.SetValue(nVTab.FindField("Mean"),nRow,theMean)
  nVTab.SetValue(nVTab.FindField("Maximum"),nRow,theMaximum)
  nVTab.SetValue(nVTab.FindField("Minimum"),nRow,theMinimum)
  nVTab.SetValue(nVTab.FindField("Range"),nRow,(theMaximum-theMinimum).Abs)
  nVTab.SetValue(nVTab.FindField("Variance"),nRow,theVariance)
  nVTab.SetValue(nVTab.FindField("StanDev"),nRow,theStdDev)
 nVTab.SetEditable(false)

 fCount=fCount+1
 end
end
end

nTable=Table.Make(nVTab)
nTable.GetWin.Open
nTable.SetName("Rate Means")
```

The results for each site from both the frequency and rate means scripts are merged into one file. This file is then merged with site descriptions to provide some literal description for interprability. Unessential fields are removed and the merged file is exported as one file containing the statistics calculated for both frequency and rate for each intersection.

For the assessment of number of draws, simple additions to the scripts above which cull out only either 625 or 50 draws is inserted. These updated scripts are run and results combined as detailed.

The files containing the frequency and rate statistics for each intersection is brought into Excel, where additional operations are performed. First, for all intersections, differences, absolute differences, and percentage differences are calculated. The total and average absolute differences are produced. Charts which display the total draws versus 625 draws and the total draws versus 50 draws are developed. These charts display comparisons of frequency means, rate means, frequency standard deviations, and rate standard deviations. This effort enables assessment of the need for large numbers of draws. Additionally, charts for all draws displaying the predicted crashes, y*, versus the actual crashes, y, and the predicted rate, λ^*, versus the actual rate, λ, are developed. Finally, various potential ranking schemes are developed from the results. These include rankings by

1. y: sort by y descending then λ descending,
2. λ: sort by λ descending then y descending,
3. y*: sort by y* descending then λ^* descending,
4. λ^*: sort by λ^* descending then y* descending,
5. abs(y*-y): sort by abs(y*-y) descending then λ^* descending, and
6. abs(λ^*- λ): sort by abs(λ^*- λ) descending then y* descdenting.

Frequency and rate densities were calculated using the following scripts. These frequency and rate densities are developed solely for display purposes, as all statistics required can be calculated through other means. Initially, the frequencies and rates for each intersection are limited to two decimals to reduce the number of different values and enable a more meaningful resultant frequency of each. The files resulting from this two decimal limiation are imported into ArcView and the individual scripts are run. Two scripts were written for each result type (e.g., crash frequency or crash rate). The first script creates densities for individual sites, the second script merges these densities into a single file or, due to dBASE column limitations, files containing 250 columns each. The results of this second script allow development of charts within Excel showing multiple sites simultaneously. Another option for visualization would be division by type.

1. Frequency Densities:

   a. Individual

```
_frequencyFileNameList=List.Make

theFrequencyTableList=List.Make
 theFrequencyTableList.Add("data_lambda_2500x1_250_07312003_a.dbf")
 theFrequencyTableList.Add("data_lambda_2500x251_500_07312003_a.dbf")
 theFrequencyTableList.Add("data_lambda_2500x501_750_07312003_a.dbf")
 theFrequencyTableList.Add("data_lambda_2500x751_1000_07312003_a.dbf")
 theFrequencyTableList.Add("data_lambda_2500x1001_1031_07312003_a.dbf")

theCWD=FileName.GetCWD

theFieldsList=List.Make
theVTabSummaryEnumList=List.Make

fCount=1
for each t in theFrequencyTableList

  theTable=av.FindDoc(t)
  theVTab = theTable.GetVTab
  theVTabFieldsList=theVTab.GetFields

  for each f in theVTabFieldsList
   if ((f.GetName="Draw").Not) then
    theField = f

    theFileName=(theCWD.AsString+"\frequencysummarizations\"+f.GetName).AsFileName
     _frequencyFileNameList.Add(theFileName)
    theVTab.Summarize(theFileName,dBASE,theField,theFieldsList,theVTabSummaryEnumList)

    fCount=fCount+1
   end
  end
end

theVTab=nil
```

   b. Merged

```
theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityrange").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 valueField=Field.Make("Value",#FIELD_DOUBLE,8,2)
  nFieldsList.Add(valueField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

for each f in _frequencyFileNameList
  fVTab=VTab.Make((f.AsString+".dbf").AsFileName,false,false)

  for each r in fVTab
    theValue=fVTab.ReturnValue(fVTab.FindField(fVTab.GetName.Left(fVTab.GetName.Count-4)),r)

    nVTab.SetEditable(true)
      nRecord=nVTab.AddRecord
      nVTab.SetValue(nVTab.FindField("Value"),nRecord,theValue)
    nVTab.SetEditable(false)
  end
end

theFieldsList=List.Make
theVTabSummaryEnumList=List.Make

theFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityrangesummary").AsFileName
nVTab.Summarize(theFileName,dBASE,nVTab.FindField("Value"),theFieldsList,theVTabSummaryEnumList)

sVTab=VTab.Make((theFileName.AsString+".dbf").AsFileName,false,false)

theMinimum=nil
theMaximum=nil
for each r in sVTab
  theValue=sVTab.ReturnValue(sVTab.FindField("Value"),r)
  if ((theValue.IsNull).Not) then
    if (theMinimum=nil) then
      theMinimum=theValue
      theMaximum=theValue
    else
      theMinimum=theMinimum min theValue
      theMaximum=theMaximum max theValue
    end
  end
end

nsFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensity").AsFileName
nsVTab=VTab.MakeNew(nsFileName,dBASE)

nsFieldsList=List.Make
 valueField=Field.Make("Value",#FIELD_DOUBLE,8,2)
  nsFieldsList.Add(valueField)

nsVTab.SetEditable(true)
 nsVTab.AddFields(nsFieldsList)
nsVTab.SetEditable(false)

theIterativeValue=theMinimum
while (theIterativeValue<=(theMaximum+1))
  nsVTab.SetEditable(true)
   nsRecord=nsVTab.AddRecord
   nsVTab.SetValue(nsVTab.FindField("Value"),nsRecord,theIterativeValue)
  nsVTab.SetEditable(false)
```

```
  theIterativeValue=theIterativeValue+0.01
end

fCount=1
for each f in _frequencyFileNameList
  fVTab=VTab.Make((f.AsString+".dbf").AsFileName,false,false)
  fBaseName=f.GetBaseName
  fJoinField=fVTab.FindField(fBaseName.AsString)

  nsVTab.Join(nsVTab.FindField("Value"),fVTab,fJoinField)
  countField=nsVTab.FindField("Count")
  countField.SetAlias(fBaseName.AsString)

  if (fCount=250) then
    dFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityjoined_1_250").AsFileName
    nsVTab.Export(dFileName,dBASE,false)
    nsVTab.UnjoinAll
  elseif (fCount=500) then
    dFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityjoined_251_500").AsFileName
    nsVTab.Export(dFileName,dBASE,false)
    nsVTab.UnjoinAll
  elseif (fCount=750) then
    dFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityjoined_501_750").AsFileName
    nsVTab.Export(dFileName,dBASE,false)
    nsVTab.UnjoinAll
  elseif (fCount=1000) then
    dFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityjoined_751_1000").AsFileName
    nsVTab.Export(dFileName,dBASE,false)
    nsVTab.UnjoinAll
  elseif (fCount=1031) then
    dFileName=(theCWD.AsString+"\frequencysummarizations\frequencydensityjoined_1001_1031").AsFileName
    nsVTab.Export(dFileName,dBASE,false)
    nsVTab.UnjoinAll
  end

  fCount=fCount+1
end
```

2. Rate Densities:

a. Individual

```
_rateFileNameList=List.Make

theVolumeTableList=List.Make
 theVolumeTableList.Add("data_lambdavolume_2500x1_250_07312003_a.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x251_500_07312003_a.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x501_750_07312003_a.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x751_1000_07312003_a.dbf")
 theVolumeTableList.Add("data_lambdavolume_2500x1001_1031_07312003_a.dbf")

theCWD=FileName.GetCWD

theFieldsList=List.Make
theVTabSummaryEnumList=List.Make

fCount=1
for each t in theVolumeTableList

  theTable=av.FindDoc(t)
  theVTab = theTable.GetVTab
  theVTabFieldsList=theVTab.GetFields

  for each f in theVTabFieldsList
    if ((f.GetName="Draw").Not) then
      theField = f
```

```
    theFileName=(theCWD.AsString+"\ratesummarizations\"+f.GetName).AsFileName
    _rateFileNameList.Add(theFileName)
    theVTab.Summarize(theFileName,dBASE,theField,theFieldsList,theVTabSummaryEnumList)

    fCount=fCount+1
   end
  end
end

theVTab=nil
```

b. Merged

```
theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\ratesummarizations\ratedensityrange").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 valueField=Field.Make("Value",#FIELD_DOUBLE,8,2)
  nFieldsList.Add(valueField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

for each f in _rateFileNameList
  fVTab=VTab.Make((f.AsString+".dbf").AsFileName,false,false)

  for each r in fVTab
    theValue=fVTab.ReturnValue(fVTab.FindField(fVTab.GetName.Left(fVTab.GetName.Count-4)),r)

    nVTab.SetEditable(true)
      nRecord=nVTab.AddRecord
      nVTab.SetValue(nVTab.FindField("Value"),nRecord,theValue)
    nVTab.SetEditable(false)
  end
end

theFieldsList=List.Make
theVTabSummaryEnumList=List.Make

theFileName=(theCWD.AsString+"\ratesummarizations\ratedensityrangesummary").AsFileName
nVTab.Summarize(theFileName,dBASE,nVTab.FindField("Value"),theFieldsList,theVTabSummaryEnumList)

sVTab=VTab.Make((theFileName.AsString+".dbf").AsFileName,false,false)

theMinimum=nil
theMaximum=nil
for each r in sVTab
  theValue=sVTab.ReturnValue(sVTab.FindField("Value"),r)
  if ((theValue.IsNull).Not) then
    if (theMinimum=nil) then
      theMinimum=theValue
      theMaximum=theValue
    else
      theMinimum=theMinimum min theValue
      theMaximum=theMaximum max theValue
    end
  end
end

nsFileName=(theCWD.AsString+"\ratesummarizations\ratedensity").AsFileName
nsVTab=VTab.MakeNew(nsFileName,dBASE)

nsFieldsList=List.Make
 valueField=Field.Make("Value",#FIELD_DOUBLE,8,2)
```

```
  nsFieldsList.Add(valueField)

 nsVTab.SetEditable(true)
  nsVTab.AddFields(nsFieldsList)
 nsVTab.SetEditable(false)

 theIterativeValue=theMinimum
 while (theIterativeValue<=(theMaximum+1))
  nsVTab.SetEditable(true)
   nsRecord=nsVTab.AddRecord
   nsVTab.SetValue(nsVTab.FindField("Value"),nsRecord,theIterativeValue)
  nsVTab.SetEditable(false)

  theIterativeValue=theIterativeValue+0.01
 end

 fCount=1
 for each f in _rateFileNameList
  fVTab=VTab.Make((f.AsString+".dbf").AsFileName,false,false)
  fBaseName=f.GetBaseName
  fJoinField=fVTab.FindField(fBaseName.AsString)

  nsVTab.Join(nsVTab.FindField("Value"),fVTab,fJoinField)
  countField=nsVTab.FindField("Count")
  countField.SetAlias(fBaseName.AsString)

  if (fCount=250) then
   dFileName=(theCWD.AsString+"\ratesummarizations\ratedensityjoined_1_250").AsFileName
   nsVTab.Export(dFileName,dBASE,false)
   nsVTab.UnjoinAll
  elseif (fCount=500) then
   dFileName=(theCWD.AsString+"\ratesummarizations\ratedensityjoined_251_500").AsFileName
   nsVTab.Export(dFileName,dBASE,false)
   nsVTab.UnjoinAll
  elseif (fCount=750) then
   dFileName=(theCWD.AsString+"\ratesummarizations\ratedensityjoined_501_750").AsFileName
   nsVTab.Export(dFileName,dBASE,false)
   nsVTab.UnjoinAll
  elseif (fCount=1000) then
   dFileName=(theCWD.AsString+"\ratesummarizations\ratedensityjoined_751_1000").AsFileName
   nsVTab.Export(dFileName,dBASE,false)
   nsVTab.UnjoinAll
  elseif (fCount=1031) then
   dFileName=(theCWD.AsString+"\ratesummarizations\ratedensityjoined_1001_1031").AsFileName
   nsVTab.Export(dFileName,dBASE,false)
   nsVTab.UnjoinAll
  end

  fCount=fCount+1
 end
```

The files created using these scripts were then brought into Excel. Within Excel, individual charts or combination charts are simple to create.

Two different variations on typology were developed. The first created typologies based on individal values of each covariate. The second produced typologies based on all covariates considered in concert.

For the first type of typology, three separate ArcView Avenue scripts were coded for development of typologies. The first creates summarizations by type, based on individual covariate values including base covariate values. This script identifies the sites associated with each covariate value. The second script, using the results from the first script, develops tables containing the frequencies for each draw for each site. The third, similar to the second script, develops tables containing the rates for each draw for each site.

1. Create Type Summarizations:

```
dvTable=av.FindDoc("data_08122003_dummyvariables.dbf")
 dvVTab=dvTable.GetVTab
  allFieldsList=dvVTab.GetFields

dvFieldsList=List.Make
for each f in allFieldsList
  if (((f.GetName="Id") or
     (f.GetName="NorthSouth") or
     (f.GetName="EastWest") or
     (f.GetName="City") or
     (f.GetName="IntID")).Not) then
    dvFieldsList.Add(f)
  end
end

theCWD=FileName.GetCWD

theFieldsList=List.Make
theVTabSummaryEnumList=List.Make

_intersectiontypeFileNameList=List.Make
for each f in dvFieldsList
  fFileName=(theCWD.AsString+"\intersectiontyping\"+f.GetName+"_typesummary").AsFileName
  summaryVTab=dvVTab.Summarize(fFileName,dBASE,f,theFieldsList,theVTabSummaryEnumList)

  for each s in summaryVTab
    fCount=summaryVTab.ReturnValue(summaryVTab.FindField(f.GetName),s)
    if ((fCount=0).Not) then
      fQuery="(["+f.GetName+"] ="++fCount.AsString++")"
      dvVTab.Query(fQuery,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)

      theFileName=(theCWD.AsString+"\intersectiontyping\"+f.GetName+"_"+fCount.AsString+"_typesummary").AsFileName
      _intersectiontypeFileNameList.Add(theFileName)
      dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)
    end
    fCount=fCount+1
  end
  fQuery="(["+f.GetName+"] = 999999 )"
  dvVTab.Query(fQuery,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
end

tdirExpr="([TDir] = 0)"
 dvVTab.Query(tdirExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\tdirbase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

iclassExpr="([IClass1] = 0)"
 dvVTab.Query(iclassExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\iclassbase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

geoExpr="([Geo1] = 0) and ([Geo2] = 0) and ([Geo3] = 0) and ([Geo4] = 0)"
 dvVTab.Query(geoExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\geobase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

topoExpr="([Topo] = 0)"
 dvVTab.Query(topoExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\topobase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

zoneExpr="([Zone1] = 0) and ([Zone2] = 0) and ([Zone3] = 0) and ([Zone4] = 0) and([Zone5] = 0) and ([Zone6] = 0)"
 dvVTab.Query(zoneExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\zonebase_0000_typesummary").AsFileName
```

```
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

stypeExpr="([SType] = 0)"
 dvVTab.Query(stypeExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\stypebase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

contExpr="([Cont1] = 0) and ([Cont2] = 0) and ([Cont3] = 0) and ([Cont4] = 0) and ([Cont5] = 0) and ([Cont6] = 0) and
([Cont7] = 0)"
 dvVTab.Query(contExpr,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
 theFileName=(theCWD.AsString+"\intersectiontyping\contbase_0000_typesummary").AsFileName
 _intersectiontypeFileNameList.Add(theFileName)
 dvVTab.Summarize(theFileName,dBASE,dvVTab.FindField("IntID"),theFieldsList,theVTabSummaryEnumList)

fQuery="([IntID] = 999999 )"
dvVTab.Query(fQuery,dvVTab.GetSelection,#VTAB_SELTYPE_NEW)
```

2. Frequency Type Files Creator:

```
fTable250=av.FindDoc("data_lambda_2500x1_250_07312003_a.dbf")
 fVTab250=fTable250.GetVTab
fTable500=av.FindDoc("data_lambda_2500x251_500_07312003_a.dbf")
 fVTab500=fTable500.GetVTab
fTable750=av.FindDoc("data_lambda_2500x501_750_07312003_a.dbf")
 fVTab750=fTable750.GetVTab
fTable1000=av.FindDoc("data_lambda_2500x751_1000_07312003_a.dbf")
 fVTab1000=fTable1000.GetVTab
fTable1031=av.FindDoc("data_lambda_2500x1001_1031_07312003_a.dbf")
 fVTab1031=fTable1031.GetVTab

theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\intersectiontyping\drawtemplate").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 drawField=Field.Make("Draw",#FIELD_SHORT,5,0)
  nFieldsList.Add(drawField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

dCount=1
while (dCount<=2500)
  nVTab.SetEditable(true)
   nRecord=nVTab.AddRecord
   nVTab.SetValue(nVTab.FindField("Draw"),nRecord,dCount)
  nVTab.SetEditable(false)
  dCount=dCount+1
end

for each i in _intersectiontypeFileNameList
  iVTab=VTab.Make((i.AsString+".dbf").AsFileName,false,false)
  iBaseName=i.GetBaseName

  iColumn250List=List.Make
  iColumn500List=List.Make
  iColumn750List=List.Make
  iColumn1000List=List.Make
  iColumn1031List=List.Make
  for each r in iVTab
    iValue=iVTab.ReturnValue(iVTab.FindField("IntID"),r)
    iColumn="Col"+iValue.AsString
    if (iValue<=250) then
```

```
    iColumn250List.Add(iColumn)
  elseif (iValue<=500) then
    iColumn500List.Add(iColumn)
  elseif (iValue<=750) then
    iColumn750List.Add(iColumn)
  elseif (iValue<=1000) then
    iColumn1000List.Add(iColumn)
  else
    iColumn1031List.Add(iColumn)
  end
end

iColumn250List.Add("Draw")
iColumn500List.Add("Draw")
iColumn750List.Add("Draw")
iColumn1000List.Add("Draw")
iColumn1031List.Add("Draw")

dFileNamesList=List.Make

iCount=250
while (iCount<=1250)
  if (iCount<=250) then
    nVTab.Join(nVTab.FindField("Draw"),fVTab250,fVTab250.FindField("Draw"))
    nFieldsList=nVTab.GetFields
    for each n in nFieldsList
      if ((iColumn250List.FindByValue(n.GetName)>=0).Not) then
        n.SetVisible(false)
      end
    end
  elseif (iCount<=500) then
    nVTab.Join(nVTab.FindField("Draw"),fVTab500,fVTab500.FindField("Draw"))
    nFieldsList=nVTab.GetFields
    for each n in nFieldsList
      if ((iColumn500List.FindByValue(n.GetName)>=0).Not) then
        n.SetVisible(false)
      end
    end
  elseif (iCount<=750) then
    nVTab.Join(nVTab.FindField("Draw"),fVTab750,fVTab750.FindField("Draw"))
    nFieldsList=nVTab.GetFields
    for each n in nFieldsList
      if ((iColumn750List.FindByValue(n.GetName)>=0).Not) then
        n.SetVisible(false)
      end
    end
  elseif (iCount<=1000) then
    nVTab.Join(nVTab.FindField("Draw"),fVTab1000,fVTab1000.FindField("Draw"))
    nFieldsList=nVTab.GetFields
    for each n in nFieldsList
      if ((iColumn1000List.FindByValue(n.GetName)>=0).Not) then
        n.SetVisible(false)
      end
    end
  else
    nVTab.Join(nVTab.FindField("Draw"),fVTab1031,fVTab1031.FindField("Draw"))
    nFieldsList=nVTab.GetFields
    for each n in nFieldsList
      if ((iColumn1031List.FindByValue(n.GetName)>=0).Not) then
        n.SetVisible(false)
      end
    end
  end

  if (iCount<=250) then
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_1_250f").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
```

```
    elseif (iCount<=500) then
     dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_251_500f").AsFileName
     nVTab.Export(dFileName,dBASE,false)
     nVTab.UnjoinAll
    elseif (iCount<=750) then
     dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_501_750f").AsFileName
     nVTab.Export(dFileName,dBASE,false)
     nVTab.UnjoinAll
    elseif (iCount<=1000) then
     dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_751_1000f").AsFileName
     nVTab.Export(dFileName,dBASE,false)
     nVTab.UnjoinAll
    else
     dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_1001_1031f").AsFileName
     nVTab.Export(dFileName,dBASE,false)
     nVTab.UnjoinAll
    end
    dFileNamesList.Add(dFileName)
    iCount=iCount+250
  end
end
```

3. Rate Type Files Creator:

```
fTable250=av.FindDoc("data_lambdavolume_2500x1_250_07312003_a.dbf")
 fVTab250=fTable250.GetVTab
fTable500=av.FindDoc("data_lambdavolume_2500x251_500_07312003_a.dbf")
 fVTab500=fTable500.GetVTab
fTable750=av.FindDoc("data_lambdavolume_2500x501_750_07312003_a.dbf")
 fVTab750=fTable750.GetVTab
fTable1000=av.FindDoc("data_lambdavolume_2500x751_1000_07312003_a.dbf")
 fVTab1000=fTable1000.GetVTab
fTable1031=av.FindDoc("data_lambdavolume_2500x1001_1031_07312003_a.dbf")
 fVTab1031=fTable1031.GetVTab

theCWD=FileName.GetCWD

nFileName=(theCWD.AsString+"\intersectiontyping\drawtemplate").AsFileName
nVTab=VTab.MakeNew(nFileName,dBASE)

nFieldsList=List.Make
 drawField=Field.Make("Draw",#FIELD_SHORT,5,0)
  nFieldsList.Add(drawField)

nVTab.SetEditable(true)
 nVTab.AddFields(nFieldsList)
nVTab.SetEditable(false)

dCount=1
while (dCount<=2500)
  nVTab.SetEditable(true)
   nRecord=nVTab.AddRecord
   nVTab.SetValue(nVTab.FindField("Draw"),nRecord,dCount)
  nVTab.SetEditable(false)
  dCount=dCount+1
end

for each i in _intersectiontypeFileNameList
  iVTab=VTab.Make((i.AsString+".dbf").AsFileName,false,false)
  iBaseName=i.GetBaseName

  iColumn250List=List.Make
  iColumn500List=List.Make
  iColumn750List=List.Make
  iColumn1000List=List.Make
  iColumn1031List=List.Make
  for each r in iVTab
```

```
 iValue=iVTab.ReturnValue(iVTab.FindField("IntID"),r)
 iColumn="Col"+iValue.AsString
 if (iValue<=250) then
  iColumn250List.Add(iColumn)
 elseif (iValue<=500) then
  iColumn500List.Add(iColumn)
 elseif (iValue<=750) then
  iColumn750List.Add(iColumn)
 elseif (iValue<=1000) then
  iColumn1000List.Add(iColumn)
 else
  iColumn1031List.Add(iColumn)
 end
end

iColumn250List.Add("Draw")
iColumn500List.Add("Draw")
iColumn750List.Add("Draw")
iColumn1000List.Add("Draw")
iColumn1031List.Add("Draw")


iCount=250
while (iCount<=1250)
 if (iCount<=250) then
  nVTab.Join(nVTab.FindField("Draw"),fVTab250,fVTab250.FindField("Draw"))
  nFieldsList=nVTab.GetFields
  for each n in nFieldsList
   if ((iColumn250List.FindByValue(n.GetName)>=0).Not) then
    n.SetVisible(false)
   end
  end
 elseif (iCount<=500) then
  nVTab.Join(nVTab.FindField("Draw"),fVTab500,fVTab500.FindField("Draw"))
  nFieldsList=nVTab.GetFields
  for each n in nFieldsList
   if ((iColumn500List.FindByValue(n.GetName)>=0).Not) then
    n.SetVisible(false)
   end
  end
 elseif (iCount<=750) then
  nVTab.Join(nVTab.FindField("Draw"),fVTab750,fVTab750.FindField("Draw"))
  nFieldsList=nVTab.GetFields
  for each n in nFieldsList
   if ((iColumn750List.FindByValue(n.GetName)>=0).Not) then
    n.SetVisible(false)
   end
  end
 elseif (iCount<=1000) then
  nVTab.Join(nVTab.FindField("Draw"),fVTab1000,fVTab1000.FindField("Draw"))
  nFieldsList=nVTab.GetFields
  for each n in nFieldsList
   if ((iColumn1000List.FindByValue(n.GetName)>=0).Not) then
    n.SetVisible(false)
   end
  end
 else
  nVTab.Join(nVTab.FindField("Draw"),fVTab1031,fVTab1031.FindField("Draw"))
  nFieldsList=nVTab.GetFields
  for each n in nFieldsList
   if ((iColumn1031List.FindByValue(n.GetName)>=0).Not) then
    n.SetVisible(false)
   end
  end
 end


 if (iCount<=250) then
```

```
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_1_250r").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
   elseif (iCount<=500) then
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_251_500r").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
   elseif (iCount<=750) then
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_501_750r").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
   elseif (iCount<=1000) then
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_751_1000r").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
   else
    dFileName=(theCWD.AsString+"\intersectiontyping\"+iBaseName.AsString++"_1001_1031r").AsFileName
    nVTab.Export(dFileName,dBASE,false)
    nVTab.UnjoinAll
   end
   iCount=iCount+250
  end
 end
```

The files created are divided as before, due to dBASE column limitations. These files are imported into Excel where the columns in each division file are summed. The sums are compiled into one file where an average is calculated (e.g., sum divided by number of sites fitting the covariate value). These compiled results are saved. All the files for the various typologies are imported into Excel and merged. The result file is saved and imported into Excel. Density charts are developed within Excel for any grouping of typology.

For the second type of typology, a process was developed but no scripts. The process begins with querying for all sites that have the exact same site characteristics, other than volume and crash history. These sites are noted and the crash frequency and rate results for these sites are tabulated in a single table. From this table, charts may be created and conclusions drawn.

APPENDIX H. SAS CODE

A couple SAS scripts were developed to perform various portions of the research. These scripts include a script to perform the generalized linear model (GLIM) analyses, a script to create the dummy variables, a script to create the random numbers for the β initial values, a script to develop the frequencies and rates from the draws, and a script to generate the draw-based rankings. These last two were later combined.

GENMOD

Within SAS, generalized linear models (GLIMs) are modeled using PROC GENMOD. PROC GENMOD enables specification of the GLIM equation, using a combination of categorical and continuous variables, including use of an offset variable. A variety of desired output tables can be requested. The following SAS script generates results for 12 different GLIMs, only one of which was determined to be correct for the data. (Uncertainty around the exact specification of the GLIM within PROC GENMOD, along with uncertainty about GENMODs treatment of high values (e.g., volumes), generated these 12 options.)

```
PROC IMPORT
 DATAFILE ='C:\ michael\_dissertation12172001b\SAS\data_severity_conversion_deletedupdated_06072003.dbf'
 OUT = data0 REPLACE;
RUN;
*PROC PRINT DATA=data0;
*  TITLE 'Original Data';
*RUN;
DATA data1;
  SET data0;
  lndev=log(volume);
  lnv1000=log(v1000);
  lndevrange=log(devrange);
RUN;
**PROC PRINT DATA=data1;
**  TITLE 'Data 1';
**RUN;
PROC GENMOD data=data1 order=internal;
  CLASS travdir intclass geometry topography zoning surftype controls;
  MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                        LINK=log maxit=50
                                        OFFSET=volume
                                        TYPE1
                                        TYPE3
                                        CORRB
                                        COVB
                                        OBSTATS;
  TITLE 'GENMOD with Offset dev (dev=volume)';
RUN;
PROC GENMOD data=data1 order=internal;
  CLASS travdir intclass geometry topography zoning surftype controls;
  MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls volume/
DIST=poisson
                                          LINK=log maxit=50
                                          TYPE1
                                          TYPE3
                                          CORRB
                                          COVB
                                          OBSTATS;
  TITLE 'GENMOD with Continuous dev (dev=volume)';
RUN;
PROC GENMOD data=data1 order=internal;
CLASS travdir intclass geometry topography zoning surftype controls;
  MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                        LINK=log maxit=50
                                        OFFSET=lndev
                                        TYPE1
                                        TYPE3
                                        CORRB
                                        COVB
```

```
                                          OBSTATS;
 TITLE 'GENMOD with Offset ln(dev) (dev=volume)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls lndev/
DIST=poisson
                                            LINK=log maxit=50
                                            TYPE1
                                            TYPE3
                                            CORRB
                                            COVB
                                            OBSTATS;
 TITLE 'GENMOD with Continuous ln(dev) (dev=volume)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                          LINK=log maxit=50
                                          OFFSET=v1000
                                          TYPE1
                                          TYPE3
                                          CORRB
                                          COVB
                                          OBSTATS;
 TITLE 'GENMOD with Offset dev (dev=volume/1000)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls v1000/
DIST=poisson
                                            LINK=log maxit=50
                                            TYPE1
                                            TYPE3
                                            CORRB
                                            COVB
                                            OBSTATS;
 TITLE 'GENMOD with Continuous dev (dev=volume/1000)';
RUN;
PROC GENMOD data=data1 order=internal;
CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                          LINK=log maxit=50
                                          OFFSET=lnv1000
                                          TYPE1
                                          TYPE3
                                          CORRB
                                          COVB
                                          OBSTATS;
 TITLE 'GENMOD with Offset ln(dev) (dev=volume/1000)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls lnv1000/
DIST=poisson
                                             LINK=log maxit=50
                                             TYPE1
                                             TYPE3
                                             CORRB
                                             COVB
                                             OBSTATS;
 TITLE 'GENMOD with Continuous ln(dev) (dev=volume/1000)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                          LINK=log maxit=50
                                          OFFSET=devrange
```

```
                                        TYPE1
                                        TYPE3
                                        CORRB
                                        COVB
                                        OBSTATS;
 TITLE 'GENMOD with Offset dev_range (DEV Range)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls devrange/
DIST=poisson
                                          LINK=log maxit=50
                                          TYPE1
                                          TYPE3
                                          CORRB
                                          COVB
                                          OBSTATS;
 TITLE 'GENMOD with Continuous dev_range (DEV Range)';
RUN;
PROC GENMOD data=data1 order=internal;
CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls/ DIST=poisson
                                        LINK=log maxit=50
                                        OFFSET=lndevrange
                                        TYPE1
                                        TYPE3
                                        CORRB
                                        COVB
                                        OBSTATS;
 TITLE 'GENMOD with Offset ln(dev_range) (DEV Range)';
RUN;
PROC GENMOD data=data1 order=internal;
 CLASS travdir intclass geometry topography zoning surftype controls;
 MODEL crashes=travdir intclass geometry spdlim1 spdlim2 topography zoning surftype controls lndevrange/
DIST=poisson
                                           LINK=log maxit=50
                                           TYPE1
                                           TYPE3
                                           CORRB
                                           COVB
                                           OBSTATS;
 TITLE 'GENMOD with Continuous ln(dev_range) (DEV Range)';
RUN;
```

Dummy Variable Generator.

For purposes of running BUGS, dummy variables must be generated and inserted as the data for BUGS. SAS code was utilized to convert covariate values to dummy variables, which then could be inserted into the BUGS model script. The dummy variables for each individual covariate level were written to separate files that, after some text manipulation to insert commas and put 10 values on one line (using TextPad), were inserted into the BUGS model script within the data listing.

```
OPTIONS obs=max;
* Importing data files for A, B, and C records and city names;
PROC IMPORT
 DATAFILE ='C:\ michael\_dissertation12172001b\SAS\data_severity_conversion_deletedupdated_06072003.dbf'
 OUT = data0 REPLACE;
RUN;
DATA data1;
 SET data0;
RUN;
*PROC PRINT DATA=data1;
*  TITLE 'Sorted Data';
*RUN;
PROC SORT DATA=data1 OUT=data2;
 BY ID;
```

```
RUN;
DATA data3 (keep=ID NorthSouth EastWest tdir iclass geo1 geo2 geo3 geo4
            spdlim1 spdlim2 topo zone1 zone2 zone3 zone4 zone5 zone6 stype
            cont1 cont2 cont3 cont4 cont5 cont6 cont7 crashes city volume
            devrange v1000 rate fcrashes icrashes pdocrashes injuries fatalities
            majinj mininj possinj unkinj propdamage oseverity nseverity citynumber
            nodeid raterange nsevrange);
 SET data2;
 IF travdir=1 THEN tdir=1;
  ELSE tdir=0;
 FORMAT tdir 1.0;
 IF intclass=1 THEN iclass=1;
  ELSE iclass=0;
 FORMAT iclass 1.0;
 IF geometry=1 THEN geo1=1;
  ELSE geo1=0;
 FORMAT geo1 1.0;
 IF geometry=2 THEN geo2=1;
  ELSE geo2=0;
 FORMAT geo2 1.0;
 IF geometry=3 THEN geo3=1;
  ELSE geo3=0;
 FORMAT geo3 1.0;
 IF geometry=4 THEN geo4=1;
  ELSE geo4=0;
 FORMAT geo4 1.0;
 IF topography=1 THEN topo=1;
  ELSE topo=0;
 FORMAT topo 1.0;
 IF zoning=2 THEN zone1=1;
  ELSE zone1=0;
 FORMAT zone1 1.0;
 IF zoning=3 THEN zone2=1;
  ELSE zone2=0;
 FORMAT zone2 1.0;
 IF zoning=4 THEN zone3=1;
  ELSE zone3=0;
 FORMAT zone3 1.0;
 IF zoning=5 THEN zone4=1;
  ELSE zone4=0;
 FORMAT zone4 1.0;
 IF zoning=6 THEN zone5=1;
  ELSE zone5=0;
 FORMAT zone5 1.0;
 IF zoning=7 THEN zone6=1;
  ELSE zone6=0;
 FORMAT zone6 1.0;
 IF surftype=1 THEN stype=1;
  ELSE stype=0;
 FORMAT stype 1.0;
 IF controls=1 THEN cont1=1;
  ELSE cont1=0;
 FORMAT cont1 1.0;
 IF controls=2 THEN cont2=1;
  ELSE cont2=0;
 FORMAT cont2 1.0;
 IF controls=3 THEN cont3=1;
  ELSE cont3=0;
 FORMAT cont3 1.0;
 IF controls=4 THEN cont4=1;
  ELSE cont4=0;
 FORMAT cont4 1.0;
 IF controls=5 THEN cont5=1;
  ELSE cont5=0;
 FORMAT cont5 1.0;
 IF controls=6 THEN cont6=1;
  ELSE cont6=0;
 FORMAT cont6 1.0;
```

```
 IF controls=7 THEN cont7=1;
  ELSE cont7=0;
 FORMAT cont7 1.0;
RUN;
DATA data4;
 RETAIN ID NorthSouth EastWest tdir iclass geo1 geo2 geo3 geo4
     spdlim1 spdlim2 topo zone1 zone2 zone3 zone4 zone5 zone6 stype
     cont1 cont2 cont3 cont4 cont5 cont6 cont7 crashes city volume
     devrange v1000 rate fcrashes icrashes pdocrashes injuries fatalities
     majinj mininj possinj unkinj propdamage oseverity nseverity citynumber
     nodeid raterange nsevrange;
 SET data3;
RUN;
DATA database_tdir (keep=tdir);
 SET data4;
RUN;
DATA database_iclass (keep=iclass);
 SET data4;
RUN;
DATA database_geo1 (keep=geo1);
 SET data4;
RUN;
DATA database_geo2 (keep=geo2);
 SET data4;
RUN;
DATA database_geo3 (keep=geo3);
 SET data4;
RUN;
DATA database_geo4 (keep=geo4);
 SET data4;
RUN;
DATA database_spdlim1 (keep=spdlim1);
 SET data4;
RUN;
DATA database_spdlim2 (keep=spdlim2);
 SET data4;
RUN;
DATA database_topo (keep=topo);
 SET data4;
RUN;
DATA database_zone1 (keep=zone1);
 SET data4;
RUN;
DATA database_zone2 (keep=zone2);
 SET data4;
RUN;
DATA database_zone3 (keep=zone3);
 SET data4;
RUN;
DATA database_zone4 (keep=zone4);
 SET data4;
RUN;
DATA database_zone5 (keep=zone5);
 SET data4;
RUN;
DATA database_zone6 (keep=zone6);
 SET data4;
RUN;
DATA database_stype (keep=stype);
 SET data4;
RUN;
DATA database_cont1 (keep=cont1);
 SET data4;
RUN;
DATA database_cont2 (keep=cont2);
 SET data4;
RUN;
DATA database_cont3 (keep=cont3);
```

```
 SET data4;
RUN;
DATA database_cont4 (keep=cont4);
 SET data4;
RUN;
DATA database_cont5 (keep=cont5);
 SET data4;
RUN;
DATA database_cont6 (keep=cont6);
 SET data4;
RUN;
DATA database_cont7 (keep=cont7);
 SET data4;
RUN;
DATA database_volume (keep=volume);
 SET data4;
RUN;
DATA database_devrange (keep=devrange);
 SET data4;
RUN;
DATA database_v1000 (keep=v1000);
 SET data4;
RUN;
DATA database_crashes (keep=crashes);
 SET data4;
RUN;
PROC EXPORT
 DATA = data4
 OUTFILE =
'C:\_michael\_dissertation12172001b\SAS\data_severity_conversion_deletedupdated_06072003_dummyvariables.db
f'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_tdir
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_tdir_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_iclass
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_iclass_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_geo1
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_geo1_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_geo2
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_geo2_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_geo3
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_geo3_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_geo4
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_geo4_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_spdlim1
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_spdlim1_06072003.dbf'
 REPLACE;
RUN;
```

```
PROC EXPORT
 DATA = database_spdlim2
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_spdlim2_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_topo
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_topo_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone1
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone1_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone2
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone2_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone3
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone3_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone4
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone4_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone5
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone5_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_zone6
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_zone6_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_stype
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_stype_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont1
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont1_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont2
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont2_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont3
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont3_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont4
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont4_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont5
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont5_06072003.dbf'
```

```
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont6
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont6_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_cont7
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_cont7_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_volume
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_volume_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_devrange
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_devrange_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_v1000
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_v1000_06072003.dbf'
 REPLACE;
RUN;
PROC EXPORT
 DATA = database_crashes
 OUTFILE = 'C:\_michael\_dissertation12172001b\SAS\database_crashes_06072003.dbf'
 REPLACE;
RUN;
```

Random Number Generator.

BUGS utilizes specified initial values as starting points for its Markov Chains. These specified initial values can be chosen or they can be randomly generated. The latter option was used for this research and SAS code was used to develop sufficient values to specify initial β values for 4 separate chains and 24 covariates (e.g., $\beta_0 \rightarrow \beta_{23}$).

```
DATA one;
 DO i=1 to 96;
  x=rannor(3172)*2;
 output;
 END;
RUN;
PROC PRINT DATA=one;
 TITLE 'One';
RUN;
PROC EXPORT DATA = one OUTFILE = 'C:\_michael\_dissertation12172001c\SAS\two.dbf' REPLACE;
RUN;
```

Site Crash Frequency and Rate Calculations.

To calculate values of y* and λ* from the BUGS results (βs), additional SAS code was written. This SAS code utilizes SAS PROC IML (Interactive Matrix Language) to manipulate the matrices involved in these calculations. The process this SAS code follows is:

1. An initial IML process creates matrices from the **β** dataset and the intersection dummy variable dataset, transposes the intersection dummy variable dataset, and multiplies the **β** matrix to the transposed intersection dummy variable matrix per matrix multiplication rules. The result is a matrix containing the **<u>βx</u>** values, summed across the intersection (i.e., $\beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_i x_i$, where i is the number of covariates in the model), for each BUGS draw and each intersection (e.g., 2500 values for each of 1031 intersections). The resultant matrix has number of rows equal to the number of draws and number of columns equal to the number of intersections (e.g., a table with 2500 rows and 1031

columns). This result matrix is saved to a SAS dataset for future calculations, IML is exited, and the results from this step of the process are saved (in subset files due to a limitation of 255 columns in dBASE data tables).

2. Between the first and second IML processes, a SAS dataset containing only the daily entering volumes (DEVs) for each intersection is created. This dataset has number of rows equal to the number of intersections and one column containing the DEVs.
3. A second IML process creates matrices from the volume dataset and the **βx** dataset and develops a new unit matrix containing a row of "1"s for each draw (e.g., 1 row with 2500 column containing "1"s). The next IML step multiplies the log of the volume matrix to the unit matrix per matrix multiplication rules, creating a matrix of volumes for each draw with the volumes for each intersection in individual rows across all columns (e.g., a 1031 row x 2500 column matrix with each row representing each intersection). The IML process then transposes the volume-unit matrix to switch the rows and columns for future matrix multiplication purposes, and adds the **βx** matrix to the transposed volume-unit matrix per matrix multiplication rules. The resultant matrix contains the same number of rows and columns as the **βx** matrix (e.g., 2500 rows x 1031 columns). The result matrix is saved to a SAS dataset for future calculations, IML is exited, and the results from this step of the process are saved (in subset files due to a limitation of 255 columns in dBASE data tables).
4. A third IML process is utilized to develop a database of crash frequency draws for each intersection. This process begins by creating a matrix from the **βx**-exp$^{(volume)}$ dataset previously created. An exponential function is then applied to the **βx**-exp$^{(volume)}$ matrix, producing a new matrix which contains draws of crash frequency for each intersection. The resultant matrix contains the same number of rows and columns as the **βx** matrix (e.g., 2500 rows x 1031 columns). The result matrix is saved to a SAS dataset for future calculations, IML is exited, and the results from this step of the process are saved (in subset files due to a limitation of 255 columns in dBASE data tables).
5. A fourth, and final, IML process develops a database of crash rate draws for each intersection. The IML process again begins by creating a matrix from the previous dataset and another matrix from the volume dataset created prior to the second IML step. Next, the IML process develops a new unit matrix containing a row of "1"s for each draw (e.g., 1 row with 2500 column containing "1"s) and generates an identity matrix containing the value 1,000,000 for each intersection (e.g., a matrix containing 1031 rows and columns with the value 1,000,000 along the diagonal). The next IML step multiplies the volume matrix to the unit matrix per matrix multiplication rules, creating a matrix of volumes for each draw with the volumes for each intersection in individual rows across all columns (e.g., a 1031 row x 2500 column matrix with each row representing each intersection). This matrix is not the same matrix as was created in the second IML process because no log calculation is applied to the volume. The crash frequency matrix is then multiplied to this new volume matrix, creating a first step matrix on the path to rate calculations. The first step matrix is multiplied to the 1,000,000 identity matrix to obtain a second step matrix on the path to rate calculations. Finally, the second step matrix is divided by 365 days, which produces a final matrix containing rate draws for each intersection. The resultant matrix contains the same number of rows and columns as the **βx** matrix (e.g., 2500 rows x 1031 columns). The result matrix is saved to a SAS dataset for future calculations, IML is exited, and the results from this step of the process are saved (in subset files due to a limitation of 255 columns in dBASE data tables).

This process is enabled by the following code, which divides the output into several files due to dBASE file size limitations.

```
PROC IMPORT DATAFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 
07302003\final_beta1000_40_07292003\codachain1a.dbf' OUT = codachain1 REPLACE;
RUN;
PROC IMPORT DATAFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 
07302003\final_beta1000_40_07292003\codachain2a.dbf' OUT = codachain2 REPLACE;
RUN;
PROC IMPORT DATAFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 
07302003\final_beta1000_40_07292003\codachain3a.dbf' OUT = codachain3 REPLACE;
RUN;
```

```
PROC IMPORT DATAFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\final_beta1000_40_07292003\codachain4a.dbf' OUT = codachain4 REPLACE;
RUN;
PROC IMPORT DATAFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\dummyvariables_07312003.dbf' OUT = dummyvariables0 REPLACE;
RUN;
DATA combinedcoda0;
 SET codachain1 codachain2 codachain3 codachain4;
 draw=_n_;
RUN;
DATA dummyvariables1 (KEEP=unity tdir iclass1 geo1 geo2 geo3 geo4 spdlim1 spdlim2 topo
            zone1 zone2 zone3 zone4 zone5 zone6 stype cont1 cont2 cont3
            cont4 cont5 cont6 cont7);
 SET dummyvariables0;
 unity=1;
RUN;
DATA dummyvariables2;
 RETAIN unity tdir iclass1 geo1 geo2 geo3 geo4 spdlim1 spdlim2 topo
      zone1 zone2 zone3 zone4 zone5 zone6 stype cont1 cont2 cont3
      cont4 cont5 cont6 cont7;
 SET dummyvariables1;
RUN;
DATA combinedcoda1 (KEEP=beta0 beta01 beta02 beta03 beta04 beta05 beta06 beta07
           beta08 beta09 beta10 beta11 beta12 beta13 beta14 beta15 beta16
                                        beta17 beta18 beta19 beta20 beta21 beta22 beta23);
 SET combinedcoda0;
RUN;
PROC IML;
 USE dummyvariables2 VAR _num_;
 READ ALL VAR _num_ into DUMMYSET;

 USE combinedcoda1 VAR _num_;
 READ ALL VAR _num_ into CODASET;

 TDUMMYSET=T(DUMMYSET);

 CODADUMMY=CODASET*TDUMMYSET;

 CREATE codadummy0 FROM CODADUMMY;
 APPEND FROM CODADUMMY;
QUIT;
DATA codadummy1_250 (KEEP=col1-col250);
 SET codadummy0;
RUN;

PROC EXPORT DATA = codadummy1_250 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_23multiplied_2500x1_250_07312003.dbf' REPLACE;
RUN;
DATA codadummy251_500 (KEEP=col251-col500);
 SET codadummy0;
RUN;
PROC EXPORT DATA = codadummy251_500 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_23multiplied_2500x251_500_07312003.dbf' REPLACE;
RUN;
DATA codadummy501_750 (KEEP=col501-col750);
 SET codadummy0;
RUN;
PROC EXPORT DATA = codadummy501_750 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_23multiplied_2500x501_750_07312003.dbf' REPLACE;
RUN;
DATA codadummy751_1000 (KEEP=col751-col1000);
 SET codadummy0;
RUN;
```

```
PROC EXPORT DATA = codadummy751_1000 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_23multiplied_2500x751_1000_07312003.dbf' REPLACE;
RUN;
DATA codadummy1001_1031 (KEEP=col1001-col1031);
 SET codadummy0;
RUN;
PROC EXPORT DATA = codadummy1001_1031 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_23multiplied_2500x1001_1031_07312003.dbf' REPLACE;
RUN;

DATA volume0 (KEEP=volume);
 SET dummyvariables0;
RUN;
PROC IML;
 USE codadummy0 VAR _num_;
 READ ALL VAR _num_ into CODADUMMYSET;

 JSET=J(1,2500,1);

 USE volume0 VAR _num_;
 READ ALL VAR _num_ into VOLUMESET;

 VJSET=LOG(VOLUMESET)*JSET;

 TVJSET=T(VJSET);

 CODADUMMYVOLUME=CODADUMMYSET+TVJSET;

 CREATE codadummyvolume0 FROM CODADUMMYVOLUME;
 APPEND FROM CODADUMMYVOLUME;
QUIT;

DATA codadummyvolume1_250 (KEEP=col1-col250);
 SET codadummyvolume0;
RUN;
PROC EXPORT DATA = codadummyvolume1_250 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_vol23multiplied_2500x1_250_07312003.dbf' REPLACE;
RUN;
DATA codadummyvolume251_500 (KEEP=col251-col500);
 SET codadummyvolume0;
RUN;
PROC EXPORT DATA = codadummyvolume251_500 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_vol23multiplied_2500x251_500_07312003.dbf' REPLACE;
RUN;
DATA codadummyvolume501_750 (KEEP=col501-col750);
 SET codadummyvolume0;
RUN;
PROC EXPORT DATA = codadummyvolume501_750 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_vol23multiplied_2500x501_750_07312003.dbf' REPLACE;
RUN;
DATA codadummyvolume751_1000 (KEEP=col751-col1000);
 SET codadummyvolume0;
RUN;
PROC EXPORT DATA = codadummyvolume751_1000 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_vol23multiplied_2500x751_1000_07312003.dbf' REPLACE;
RUN;
DATA codadummyvolume1001_1031 (KEEP=col1001-col1031);
 SET codadummyvolume0;
RUN;
PROC EXPORT DATA = codadummyvolume1001_1031 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_vol23multiplied_2500x1001_1031_07312003.dbf' REPLACE;
```

```
RUN;

PROC IML;
 USE codadummyvolume0 VAR _num_;
 READ ALL VAR _num_ into CODADUMMYVOLUMESET;

 LAMBDASET=EXP(CODADUMMYVOLUMESET);

 CREATE lambda0 FROM LAMBDASET;
 APPEND FROM LAMBDASET;
QUIT;

DATA lambda1_250 (KEEP=col1-col250);
 SET lambda0;
RUN;
PROC EXPORT DATA = lambda1_250 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambda_2500x1_250_07312003.dbf' REPLACE;
RUN;
DATA lambda251_500 (KEEP=col251-col500);
 SET lambda0;
RUN;
PROC EXPORT DATA = lambda251_500 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model
- 07302003\data_lambda_2500x251_500_07312003.dbf' REPLACE;
RUN;
DATA lambda501_750 (KEEP=col501-col750);
 SET lambda0;
RUN;
PROC EXPORT DATA = lambda501_750 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model
- 07302003\data_lambda_2500x501_750_07312003.dbf' REPLACE;
RUN;
DATA lambda751_1000 (KEEP=col751-col1000);
 SET lambda0;
RUN;
PROC EXPORT DATA = lambda751_1000 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 07302003\data_lambda_2500x751_1000_07312003.dbf'
REPLACE;
RUN;
DATA lambda1001_1031 (KEEP=col1001-col1031);
 SET lambda0;
RUN;
PROC EXPORT DATA = lambda1001_1031 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambda_2500x1001_1031_07312003.dbf' REPLACE;
RUN;

PROC IML;
 USE lambda0 VAR _num_;
 READ ALL VAR _num_ into LAMBDASET;

 JSET=J(1,2500,1);
 HMILLIONSET=I(1031)*1000000;

 USE volume0 VAR _num_;
 READ ALL VAR _num_ into VOLUMESET;

 VJSET=VOLUMESET*JSET;

 TVJSET=T(VJSET);

 LV=LAMBDASET/TVJSET;
 LVMILLION=LV*MILLIONSET;
 LMDEV=LVMILLION/365;
 LAMBDAVOLUME=LMDEV;

 CREATE lambdavolume0 FROM LAMBDAVOLUME;
 APPEND FROM LAMBDAVOLUME;
QUIT;
```

```
DATA lambdavolume1_250 (KEEP=col1-col250);
 SET lambdavolume0;
RUN;
PROC EXPORT DATA = lambdavolume1_250 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambdavolume_2500x1_250_07312003.dbf' REPLACE;
RUN;
DATA lambdavolume251_500 (KEEP=col251-col500);
 SET lambdavolume0;
RUN;
PROC EXPORT DATA = lambdavolume251_500 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambdavolume_2500x251_500_07312003.dbf' REPLACE;
RUN;
DATA lambdavolume501_750 (KEEP=col501-col750);
 SET lambdavolume0;
RUN;
PROC EXPORT DATA = lambdavolume501_750 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambdavolume_2500x501_750_07312003.dbf' REPLACE;
RUN;
DATA lambdavolume751_1000 (KEEP=col751-col1000);
 SET lambdavolume0;
RUN;
PROC EXPORT DATA = lambdavolume751_1000 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambdavolume_2500x751_1000_07312003.dbf' REPLACE;
RUN;
DATA lambdavolume1001_1031 (KEEP=col1001-col1031);
 SET lambdavolume0;
RUN;
PROC EXPORT DATA = lambdavolume1001_1031 OUTFILE =
'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_lambdavolume_2500x1001_1031_07312003.dbf' REPLACE;
RUN;
```

Site Draw Rank Calculations.

Additional SAS code was written to calculate the individual draw ranks. The code written involved four primary components: matrix manipulation to obtain the expected to actual frequency differences for each draw, a loop for calculating the ranks, output of these ranks, and calculation of summary statistics. To calculate the differences for each draw, the following code was inserted at the end of the previous SAS code:

```
DATA crashes0 (KEEP=crashes);
 SET dummyvariables0;
RUN;
PROC IML;
 USE lambda0 VAR _num_;
 READ ALL VAR _num_ into LAMBDASET;

 USE crashes0 VAR _num_;
 READ ALL VAR _num_ into CRASHESSET;

 JSET=J(1,2500,1);

 JCRASHESSET=CRASHESSET*JSET;

 SITELAMBDASET=T(LAMBDASET);
 DIFFERENCESET=SITELAMBDASET-JCRASHESSET;

 CREATE jcrashes0 FROM JCRASHESSET;
 APPEND FROM JCRASHESSET;

 CREATE difference0 FROM DIFFERENCESET;
 APPEND FROM DIFFERENCESET;
QUIT;
DATA difference1;
```

```
 SET difference0;
  FORMAT site 4.0;
 site=_n_;
RUN;
```

Once these values have been calculated, a loop is run that activates a SAS macro that sorts each of 2500 columns and assigns ranks on each sorted column, resulting in 2500 ranks. This loop is inserted after the difference calculation code:

```
%LET iterations=2500;
DATA rank;
 SET difference1;
 %SORTVALUES;
RUN;
```

However, the macro must be inserted at the top of the SAS code. This macro sorts and ranks each column:

```
PROC OPTIONS OPTION=MACRO;
RUN;

%MACRO SORTVALUES;
 %DO i=1 %TO &iterations;
   PROC SORT;
    BY COL&i;
   DATA rankout;
        SET rank;
     FORMAT rank&i 4.0;
    rank&i=_n_;
       DATA rank;
        SET rankout;
 %END;
%MEND SORTVALUES;
```

The calculated ranks are output in 5 tables, due to dBASE and Excel column limitations:

```
PROC SORT DATA=rankout OUT=sortrank0;
 BY site;
RUN;
DATA sortrank1 (KEEP=rank1-rank2500);
 SET sortrank0;
RUN;
PROC IML;
 USE sortrank1 VAR _num_;
 READ ALL VAR _num_ into SORTRANKSET;

 DRAWSORTRANKSET=T(SORTRANKSET);

 CREATE drawsortrank0 FROM DRAWSORTRANKSET;
 APPEND FROM DRAWSORTRANKSET;
QUIT;
DATA drawsortrank1;
 SET drawsortrank0;
  FORMAT draw 4.0;
 draw=_n_;
RUN;
DATA drawrank1_250 (KEEP=draw col1-col250);
 SET drawsortrank1;
RUN;
PROC EXPORT DATA = drawrank1_250 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\data_drawrank1_2500x1_250_10152003.dbf' REPLACE;
RUN;
DATA drawrank251_500 (KEEP=draw col251-col500);
 SET drawsortrank1;
RUN;
```

```
PROC EXPORT DATA = drawrank251_500 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 07302003\data_drawrank1_2500x251_500_10152003.dbf' REPLACE;
RUN;
DATA drawrank501_750 (KEEP=draw col501-col750);
 SET drawsortrank1;
RUN;
PROC EXPORT DATA = drawrank501_750 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 07302003\data_drawrank1_2500x501_750_10152003.dbf' REPLACE;
RUN;
DATA drawrank751_1000 (KEEP=draw col751-col1000);
 SET drawsortrank1;
RUN;
PROC EXPORT DATA = drawrank751_1000 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 07302003\data_drawrank1_2500x751_1000_10152003.dbf' REPLACE;
RUN;
DATA drawrank1001_1031 (KEEP=draw col1001-col1031);
 SET drawsortrank1;
RUN;
PROC EXPORT DATA = drawrank1001_1031 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model - 07302003\data_drawrank1_2500x1001_1031_10152003.dbf' REPLACE;
RUN;
```

Finally, code that calculates and outputs inferential statistics is inserted at the end. This code calculates the means, standard deviations, minimums, and maximums for each site rank value:

```
PROC MEANS NOPRINT n sum mean median stddev min max range DATA=drawsortrank0;
 VAR col1-col1031;
 OUTPUT OUT=statistics0;
RUN;
DATA statistics1 (DROP=_TYPE_ _FREQ_);
 SET statistics0;
RUN;
PROC IML;
 USE statistics1 VAR _num_;
 READ ALL VAR _num_ into STATISTICSSET;

 TSTATISTICSSET=T(STATISTICSSET);

 CREATE tstatistics0 FROM  TSTATISTICSSET;
 APPEND FROM  TSTATISTICSSET;
QUIT;
DATA tstatistics1 (KEEP=site n rankmean rndrankmean rankstddev rankmin rankmax);
 SET tstatistics0;
  FORMAT site 4.0;
 site= n ;
  FORMAT n 4.0;
 n=col1;
  FORMAT rankmean 8.2;
 rankmean=col4;
  FORMAT rndrankmean 4.0;
 rndrankmean=col4;
  FORMAT rankstddev 8.2;
 rankstddev=col5;
  FORMAT rankmin 4.0;
 rankmin=col2;
  FORMAT rankmax 4.0;
 rankmax=col3;
RUN;
DATA identifiers0 (KEEP=ID site);
 SET dummyvariables0;
 SITE=INTNUMBER;
RUN;
DATA tstatistics2;
 MERGE tstatistics1 identifiers0;
 BY site;
RUN;
PROC SORT DATA=tstatistics2 OUT=tstatistics3;
```

```
 BY RANKMEAN;
RUN;
PROC EXPORT DATA = tstatistics3 OUTFILE = 'C:\_michael\_dissertation12172001c\BUGS\BUGS\Model -
07302003\statistics_freqdiffs_10162003.dbf' REPLACE;
RUN;
```

APPENDIX I. BUGS SCRIPT

The developed BUGS model script, without the 1031 site data points, listing is:

```
model

# data Count in "y_ij.txt"
# data DEV in "v_ij.txt"
# data Direction, etc. in "x_ij.txt"

{
 for (i in 1:N)
   {
     y[i] ~ dpois(lambda[i])
     log(lambda[i]) <-
log(v[i])+beta01*tdir[i]+beta02*iclass[i]+beta03*geo1[i]+beta04*geo2[i]+beta05*geo3[i]+beta06*geo4[i]+beta07*splm1[i]+bet
a08*splm2[i]+beta09*topo[i]+beta10*zone1[i]+beta11*zone2[i]+beta12*zone3[i]+beta13*zone4[i]+beta14*zone5[i]+beta15*z
one6[i]+beta16*stype[i]+beta17*cont1[i]+beta18*cont2[i]+beta19*cont3[i]+beta20*cont4[i]+beta21*cont5[i]+beta22*cont6[i]

    }
 #priors
 beta01 ~ dnorm(0,0.001)
 beta02 ~ dnorm(0,0.001)
 beta03 ~ dnorm(0,0.001)
 beta04 ~ dnorm(0,0.001)
 beta05 ~ dnorm(0,0.001)
 beta06 ~ dnorm(0,0.001)
 beta07 ~ dnorm(0,0.001)
 beta08 ~ dnorm(0,0.001)
 beta09 ~ dnorm(0,0.001)
 beta10 ~ dnorm(0,0.001)
 beta11 ~ dnorm(0,0.001)
 beta12 ~ dnorm(0,0.001)
 beta13 ~ dnorm(0,0.001)
 beta14 ~ dnorm(0,0.001)
 beta15 ~ dnorm(0,0.001)
 beta16 ~ dnorm(0,0.001)
 beta17 ~ dnorm(0,0.001)
 beta18 ~ dnorm(0,0.001)
 beta19 ~ dnorm(0,0.001)
 beta20 ~ dnorm(0,0.001)
 beta21 ~ dnorm(0,0.001)
 beta22 ~ dnorm(0,0.001)
}

list(N=1031,
    y=c(<1031 data points>),
    v=c(<1031 data points>),
    tdir=c(<1031 data points>),
    iclass=c(<1031 data points>),
    geo1=c(<1031 data points>),
    geo2=c(<1031 data points>),
    geo3=c(<1031 data points>),
    geo4=c(<1031 data points>),
    splm1=c(<1031 data points>),
    splm2=c(<1031 data points>),
    topo=c(<1031 data points>),
    zone1=c(<1031 data points>),
    zone2=c(<1031 data points>),
    zone3=c(<1031 data points>),
    zone4=c(<1031 data points>),
    zone5=c(<1031 data points>),
    zone6=c(<1031 data points>),
    stype=c(<1031 data points>),
    cont1=c(<1031 data points>),
    cont2=c(<1031 data points>),
```

```
    cont3=c(<1031 data points>),
    cont4=c(<1031 data points>),
    cont5=c(<1031 data points>),
    cont6=c(<1031 data points>),
)

#chain one initial values - generated using SAS random number generator
list(beta01=1.2880,beta02=-2.8710,beta03=-2.9383,beta04=0.3923,beta05=-0.2077,beta06=0.4018,beta07=-0.5510,beta08=-
1.5465,beta09=-3.0913,beta10=-1.0194,beta11=1.3811,beta12=-1.0746,beta13=-
1.0800,beta14=0.4911,beta15=2.6878,beta16=0.6350,beta17=0.6852,beta18=-2.6462,beta19=1.1208,beta20=2.1358,beta21=-
0.5992,beta22=1.3127
)

#chain two initial values - generated using SAS random number generator
list(beta01=-1.9954,beta02=4.0355,beta03=2.4775,beta04=-2.5707,beta05=-3.7212,beta06=0.0979,beta07=-0.9491,beta08=-
1.0394,beta09=-0.6874,beta10=-1.2695,beta11=-0.2260,beta12=-2.2889,beta13=-1.8708,beta14=-
2.0831,beta15=0.8564,beta16=-2.0565,beta17=1.8860,beta18=4.1792,beta19=-
2.0543,beta20=2.4938,beta21=0.2465,beta22=1.8234
)

#chain three initial values - generated using SAS random number generator
list(beta01=0.0194,beta02=-2.5867,beta03=-1.5558,beta04=-1.5281,beta05=-3.4857,beta06=1.5542,beta07=-
0.3723,beta08=2.2394,beta09=-1.8674,beta10=-0.5008,beta11=-0.4957,beta12=2.4419,beta13=2.3289,beta14=0.2893,beta15=-
0.4208,beta16=1.8457,beta17=-0.7085,beta18=0.4280,beta19=2.3986,beta20=-2.8244,beta21=0.5860,beta22=-0.7196
)

#chain four initial values - generated using SAS random number generator
list(beta01=-1.3340,beta02=-0.3550,beta03=-1.0239,beta04=-0.8162,beta05=-
0.7726,beta06=2.9481,beta07=1.8799,beta08=0.8282,beta09=0.4659,beta10=-1.2117,beta11=-1.1457,beta12=-
0.4753,beta13=3.1594,beta14=3.2767,beta15=0.1585,beta16=1.3547,beta17=-
2.2090,beta18=1.3456,beta19=0.1279,beta20=1.0744,beta21=-0.9976,beta22=-0.3353
)
```

APPENDIX J. RUNNING BAYES USING GIBBS SAMPLING (BUGS)

Running the Bayes Using Gibbs Sampling (BUGS) software typically involves two primary steps. The first step involves running exploratory models to determine the appropriate model script. Using test statistics available within BUGS, the model script may be improved and further tested until the appropriate script is found. The second step involves running the final model, again assessing the test statistics, and obtaining results that may be further utilized.

Exploratory Model

Running the exploratory model includes several steps. These steps can be categorized into four groups: model specification, inference sampling, model updates, and model assessment.

Model specification

1. Choose "Open..." from the "File" menu. Choose the file that contains the sample model. The BUGS code window opens with the code representing the model, data, and initial values.
2. Choose "Specification..." from the "Model" menu. The "Specification Tool" dialog opens, as shown in Figure J1.

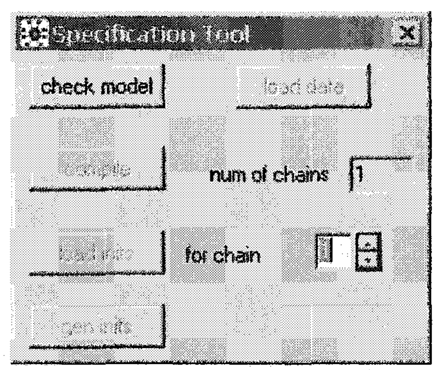


Figure J1. BUGS model specification tool

3. Within the BUGS code window, double click on the word "model" within code. The word "model" should become highlighted.
4. Click on the "check model" button within the "Specification Tool" dialog. The "load data" and "compile" buttons become enabled, as shown in Figure J2.

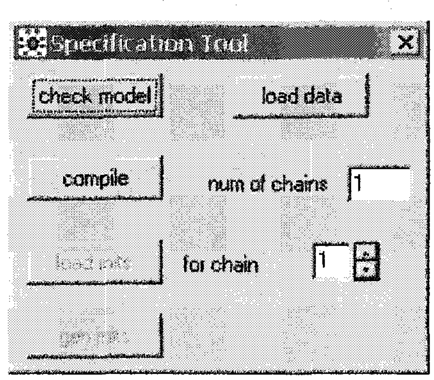


Figure J2. BUGS model specification tool – check model

5. Within the BUGS code window, double click on the word "list" that indicates the beginning of the data section. The word "list" should become highlighted.

6. Click the "load data" button within the "Specification Tool" dialog. Click the "compile" button within the "Specification Tool" dialog. The "load data" and "compile" button become disabled. The "load inits" and "gen inits" buttons become enabled, as shown in Figure J3.

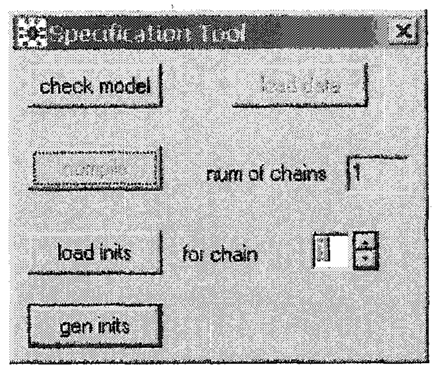


Figure J3. BUGS model specification tool – load data/compile

7. Scroll down within the BUGS code window to the initial value list. Within the BUGS code window, double click on the word "list" that indicates the beginning of the initial values section.
8. Click the "load inits" button within the "Specification Tool" dialog. The "gen inits" window become disabled, as shown in Figure J4.

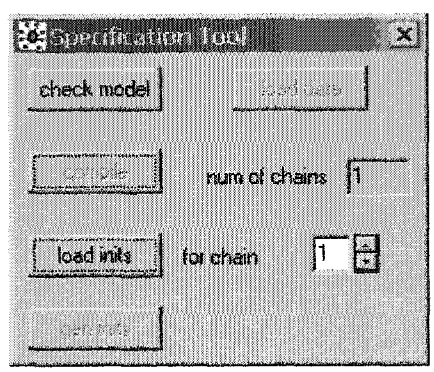


Figure J4. BUGS model specification tool – load inits

9. To view a log of the model specification steps, select "Open Log" from the "Info" menu. The log, as displayed in Figure J5, provides a statement of success or failure for each model specification step, finalizing in the statement, "model is initialized", for a successfully specified model.

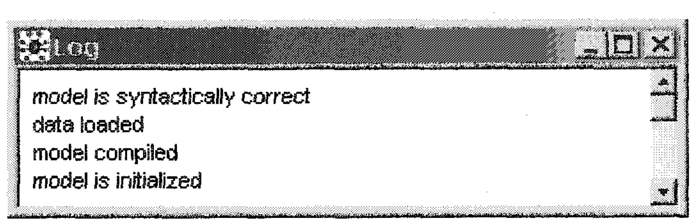


Figure J5. BUGS model – log

Inference sampling

10. Choose "Samples…" from the "Inference" menu. The "Sample Monitor Tool" dialog opens, as shown in Figure J6.

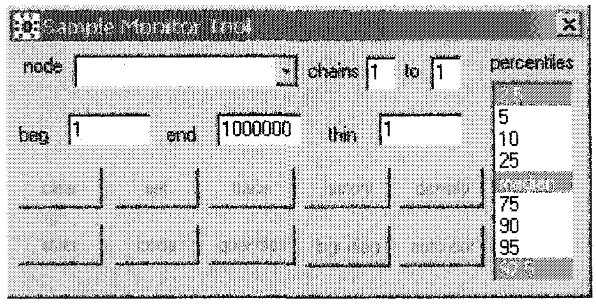


Figure J6. BUGS sample monitor tool

11. Type in each "beta" value (e.g., beta0, beta01, beta02, ..., beta21) into the "node" text insert box of the "Sample Monitor Tool" dialog, clicking on the "set" button (which will become enabled after each valid "beta" value entry) after each "beta" value entry, as shown in Figure J7. The previously entered "beta" values can be viewed by using the pull-down option to the right of the text insert box.

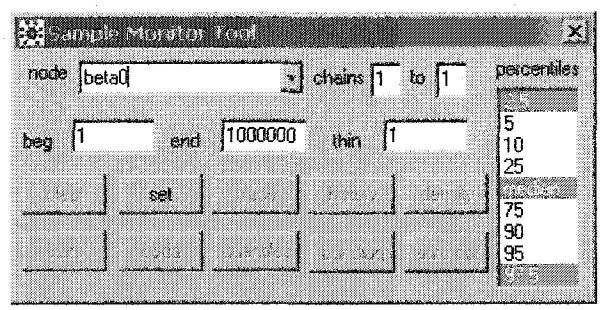


Figure J7. BUGS sample monitor tool – beta entry

12. Once each "beta" value has been entered, type "*" (asterisk) into the "node" text insert box of the "Sample Monitor Tool" dialog. The "*" (asterisk) indicates that all values have been selected for further analysis. The "clear", "trace", "history", "density", "stats", "coda", "quantiles", "GR diag", and "autoC" buttons within the "Sample Monitor Tool" dialog become enabled, as shown in Figure J8. At this point, clicking on any of these buttons would provide no information as the model has not been "updated".

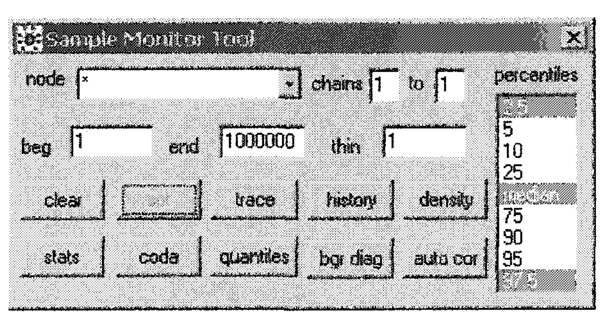


Figure J8. BUGS sample monitor tool – select all

Alternate inference tools are also available. They were not explored fully within the scope of this research. However, if they were used, setup of their monitoring would be done prior to updating the model. Steps 12-15 briefly mention each tool.

13. Choose "Fit..." from the "Inference" menu. The "Fit Tool" dialog opens. This tool may actually not be operable.
14. Choose "Correlations" from the "Inference" menu. The "Correlation Tool" dialog opens.
15. Choose "Summary..." from the "Inference" menu. The "Summary Monitor Tool" dialog opens. As was done for the "Sample Monitor Tool" dialog, type the "beta" values into the "node" text insert box of the "Summary Monitor Tool" dialog, finishing with the entry of "*" (asterisk).
16. Choose "Rank..." from the "Inference" menu. The "Rank Monitor Tool" dialog opens. As was done for the "Sample Monitor Tool" dialog and the "Summary Monitor Tool" dialog, type the "beta" values into the "node" text insert box of the "Rank Monitor Tool" dialog, finishing with the entry of "*" (asterisk). This tool may actually not be operable.

Model updates

17. Choose "Update..." from the "Model" menu. The "Update Tool" dialog opens, as shown in Figure J9. Initially, the "Update Tool" dialog indicates 1000 updates, with a refresh of 100. Set the updates at a reasonable level (e.g., 10000) that will ensure both a sufficient amount of "burn-in" time and a sufficient amount of results for further sampling and analysis.

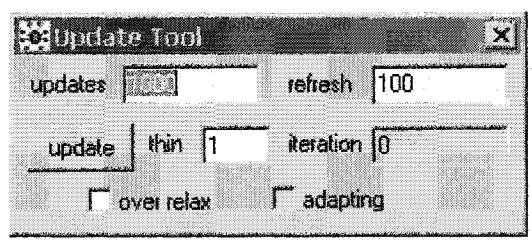


Figure J9. Update tool

18. Click on the "update" button of the "Update Tool" dialog. Wait for the update run to finish. Progress is indicated in the "iteration" display text box.

Model assessment

19. On the "Sample Monitor Tool" click on buttons of interest in turn:
   a. The "trace" button shows the time series of the beta draws as updates progress, but only the last 200 draws. The trace output is less useful than the history output as it is for such a short interval. A sample trace output is shown in Figure J10.

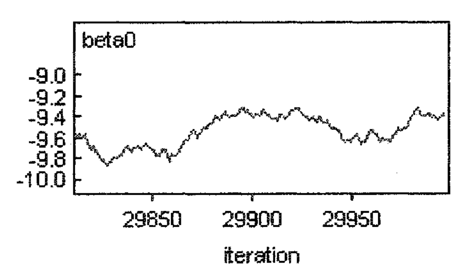


Figure J10. Sample trace diagram

The horizontal scale, as noted, displays the iteration of the updates displayed. The vertical scale shows the beta value as the Markov Chain "wanders". Selecting the "trace" button would display a 200 draw time series for each beta selected in the Sample Monitor Tool (i.e., all betas if "*" were entered in the node box of the Sample Monitor Tool).

b. The "history" button shows the time series of the beta draws over all updates. Considering the time series is helpful in assessment of model convergence. A sample history output is shown in Figure J11.

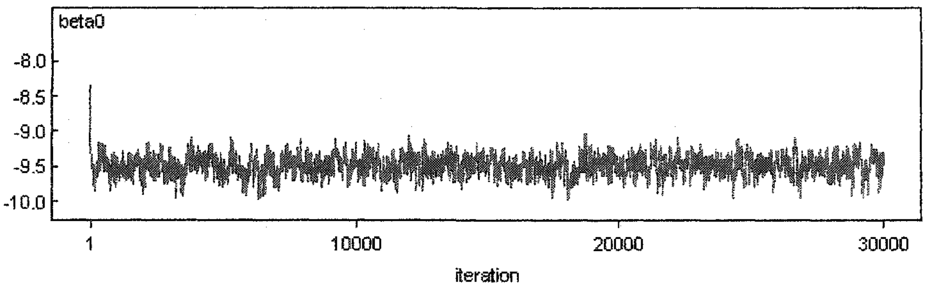


Figure J11. Sample history diagram

The horizontal scale, as noted, displays the iteration of the updates displayed. The vertical scale shows the beta value as the Markov Chain "wanders". Selecting the "history" button would display a time series for each beta selected in the Sample Monitor Tool (i.e., all betas if "*" were entered in the node box of the Sample Monitor Tool). In the displayed history, there is no indication that the model did not converge as the values for beta0 wander around –9.5 fairly consistently for all 30,000 draws.

c. The "density" button displays the posterior distribution of the betas. Essentially, the densities displayed are smoothed histograms of the frequency of each beta value. From this we can draw initial conjectures about significance, mean, standard deviation, and probabilities. Using the coda (discussed in 18e. below), the densities can be redeveloped using spreadsheet software (e.g., MicroSoft™ Excel). A sample density output is shown in Figure J12. Sample Density Diagram.

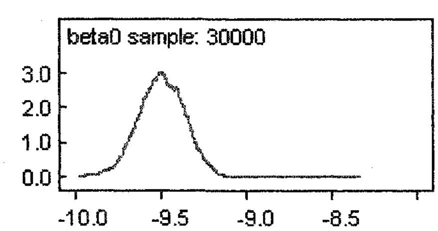


Figure J12. Sample density diagram

The horizontal scale represents the sample values and the vertical scale the frequency of each sample value. Densities that do not cross 0 are considered significant, as an initial assessment. For example, for the displayed density, the mean is roughly –9.5 and the value of beta0 varies from –9.2 to –9.8. Also, with 100% confidence it can be said that a variable associated with this density tends to reduce the log of the crash rate and that this reduction is 9.5 per unit increase in the variable.

If the distribution crossed 0, the assertion of confidence is divided, the percentage of the distribution in the positive range indicated a chance of increase and the other percentage to a decrease. For example, if 60% of the distribution were in the positive range and 40% in the negative range, there is a 60% chance that the log of the crash rate increases and a 40% chance that the log of the crash rate decreases. This example indicates essentially no information as to the true result. However, if the split were 95% vs. 5%, we would be much more confident of the true affect.

d. The "stats" button shows the statistics for each beta. The statistics displayed include mean, standard deviation, MC (Monte-Carlo) error, the 2.5%, median, and 97.5% values, the start points for each "beta", and the sample for each "beta". The combination of the 2.5% and 97.5% values help indicate further information about significance. A sample stats output is shown in Figure J13.

node	mean	sd	MC error	2.5%	median	97.5%	start	sample
beta0	-9.498	0.1367	0.005647	-9.77	-9.497	-9.24	1	30000
beta01	0.1795	0.02778	2.948E-4	0.126	0.1792	0.2346	1	30000
beta02	-0.04781	0.02613	4.264E-4	-0.09883	-0.04777	0.003361	1	30000
beta03	-4.925E-5	0.03185	1.849E-4	-0.06209	6.148E-5	0.06231	1	30000
beta04	7.608E-4	0.03179	4.535E-4	-0.06234	9.894E-4	0.06254	1	30000
beta05	-1.79E-4	0.03141	1.957E-4	-0.06153	-1.336E-4	0.06152	1	30000
beta06	1.338E-5	0.0315	1.818E-4	-0.06174	-2.082E-4	0.06148	1	30000
beta07	0.01153	0.01764	6.729E-4	-0.02259	0.01145	0.04649	1	30000
beta08	0.1897	0.0202	6.456E-4	0.1498	0.1899	0.2285	1	30000
beta09	-0.008689	0.03138	4.461E-4	-0.07073	-0.008505	0.05326	1	30000
beta10	0.09764	0.02528	2.071E-4	0.04833	0.09766	0.1473	1	30000
beta11	0.07954	0.0292	1.809E-4	0.02233	0.07955	0.1364	1	30000
beta12	0.01055	0.02996	1.737E-4	-0.0481	0.01031	0.06946	1	30000
beta13	-0.02031	0.03059	1.743E-4	-0.08031	-0.02025	0.0398	1	30000
beta14	0.01457	0.03024	1.699E-4	-0.04407	0.01455	0.07391	1	30000
beta15	-3.755E-4	0.02982	1.939E-4	-0.05937	-2.431E-4	0.05795	1	30000
beta16	0.03728	0.02583	3.199E-4	-0.01324	0.03727	0.0876	1	30000
beta17	0.2067	0.02654	2.652E-4	0.155	0.2067	0.2594	1	30000
beta18	0.06264	0.02809	1.728E-4	0.00713	0.06284	0.117	1	30000
beta19	0.04733	0.02938	2.014E-4	-0.01027	0.0474	0.105	1	30000
beta20	-0.008043	0.03086	2.007E-4	-0.06846	-0.008125	0.05274	1	30000
beta21	-0.09828	0.02843	2.143E-4	-0.1543	-0.09819	-0.04232	1	30000
beta22	-0.1723	0.02896	2.208E-4	-0.2285	-0.1721	-0.1158	1	30000
beta23	-5.381E-4	0.03134	1.793E-4	-0.06285	-2.189E-4	0.06056	1	30000

Figure J13. Sample statistics output

In Figure J13, the beta values correspond to the following variables:

- B_0 → the intercept term,
- B_1 → Travel Direction: 4-way,
- B_2 → Intersection Class: municipal with municipal,
- B_3 → Geometry: single-lane,
- B_4 → Geometry: multi-lane,
- B_5 → Geometry: single-lane w/ one-way,
- B_6 → Geometry: multi-lane w/one-way,
- B_7 → Speed Limit: Major/Highest ,
- B_8 → Speed Limit: Minor/Highest,
- B_9 → Topography: Level,
- B_{10} → Zoning: Business/Manufacturing,
- B_{11} → Zoning: School,
- B_{12} → Zoning: Recreational,
- B_{13} → Zoning: Hospital,
- B_{14} → Zoning: Church/Cemetary,
- B_{15} → Zoning: Parking Lot,
- B_{16} → Surface Type: Asphaltic Cement Concrete (ACC),
- B_{17} → Controls: 4-way Signal,
- B_{18} → Controls: 3-way Signal,
- B_{19} → Controls: 1-/2-way Signal,
- B_{20} → Controls: 3-/4-way Stop,
- B_{21} → Controls: 2-way Stop,
- B_{22} → Controls: 1-way Stop, and
- B_{23} → Controls: Yield,

The base values corresponding to each categorization reflected above are:

- Travel Direction: 3-way,
- Intersection Class: non-municipal,
- Geometry: Offset T,
- Topography: Grade,
- Zoning: Residential/Normal,
- Surface Type: Portland Cement Concrete (PCC), and
- Controls: None

These base values become the basis for interpretation for each categorization, as is typical for dummy variables. Note that Speed Limit: Major and Speed Limit: Minor, because they are continuous variables, do not have base values.

As stated, standard sample statistics are obtainable from this output. Additionally, considering each beta's 2.5% and 97.5% values, an initial indication of variable significance is facilitated in that, as with the density, pairings of the 2.5% and 97.5% that do not cross 0 indicate 100% confidence of positive or negative association. From this sample stats output, betas indicated as being significant include beta0, beta01, beta08, beta10, beta11, beta17, beta18, beta21, and beta22. These must be further analyzed and paired with their base variables for interpretation.

If multiple sample models are run, with the only difference being adjusted prior variances for the **β**s (i.e., changing the variance from 1000 to 100), then the "stats" button mean values for each **β** can be compared between the two runs, with a major difference indicating some problem with the model.

e. The "coda" button displays two windows: a "coda index" window and a "coda" window. "Coda" are the draws resulting from running the model within BUGS. The "coda index" window shows the relative location for the draws related to each "beta" within the "coda" window. A sample coda index output is shown in Figure J14. Sample Coda Index.

beta0	1	30000
beta01	30001	60000
beta02	60001	90000
beta03	90001	120000
beta04	120001	150000
beta05	150001	180000
beta06	180001	210000
beta07	210001	240000
beta08	240001	270000
beta09	270001	300000
beta10	300001	330000
beta11	330001	360000
beta12	360001	390000
beta13	390001	420000
beta14	420001	450000
beta15	450001	480000
beta16	480001	510000
beta17	510001	540000
beta18	540001	570000
beta19	570001	600000
beta20	600001	630000
beta21	630001	660000
beta22	660001	690000
beta23	690001	720000

Figure J14. Sample coda index

This sample coda index shows that the beta0 draws are shown in rows 1 through 30,000 of the coda chain.

The "coda" window contains the draws from each update for each "beta". The "coda" window contains two columns of information, one to indicate which update the draw pertains to and the other containing the draws. These values can be easily brought into spreadsheet software (e.g., MicroSoft™ Excel). for further use, such as calculation of dependent variable draws for each site. A sample of the coda output is shown in Figure J15.

1	-8.349
2	-8.497
3	-8.544
4	-8.587
5	-8.625
6	-8.672
7	-8.714
8	-8.745
9	-8.795
10	-8.845
11	-8.88
12	-8.941
13	-8.952
14	-8.959
15	-8.921
16	-8.975
17	-8.978
18	-8.978
19	-8.999
20	-9.057
21	-9.055
22	-9.12
23	-9.152
24	-9.179
25	-9.181

Figure J15. Sample coda output

This sample displays the first 25 draws from the beta0. Each beta would have similar listings of individual draws for each iteration of the update, minus any thinning.

f. The "quantiles" button graphically displays the running quantiles for all draws. This running quantile graphic displays the relative stability of the updates. It also helps in determining model convergence. A sample quantiles output is shown in Figure J16. Sample Quantiles Output.

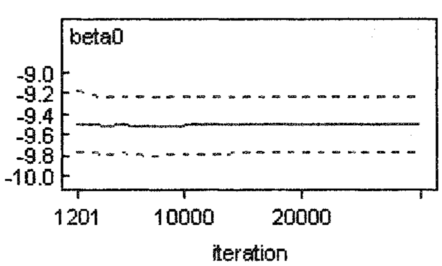


Figure J16. Sample quantiles output

The horizontal scale, as noted, displays the iteration of the updates displayed. The vertical scale shows the beta value as the Markov Chain "wanders". Selecting the "quantiles" button would display the quantiles for each beta selected in the Sample Monitor Tool (i.e., all betas if "*" were entered in the node box of the Sample Monitor Tool). The graphic displays, by a solid line, the mean over each draw and, by dotted lines, the quantiles. The quantile diagram displayed indicates convergence of the model for this variable.

g. The "bgr" button graphically displays the Gelman-Rubin statistic for all draws. This button does not function for a single chain but will function for multiple draws. The Gelman-Rubin statistic graphic helps in visualization of multi-chain convergence.

h. The "autoC" button displays the autocorrelation for each beta. Simultaneously considering these autocorrelation charts allows the determination of which updates should be sampled from for further statistical analysis, based on minimization of the autocorrelation of significant variables. The sampling is referred to as "thinning" in BUGS. A sample autocorrelation output is shown in Figure J17.

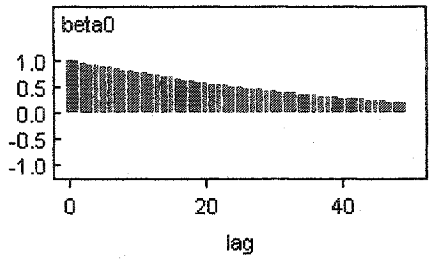


Figure J17. Sample autocorrelation output

The horizontal scale, as noted, displays the iteration of the updates displayed. The vertical scale shows the autocorrelation value as the Markov Chain "wanders". Selecting the "autoC" button would display a autocorrelation diagram for each beta selected in the Sample Monitor Tool (i.e., all betas if "*" were entered in the node box of the Sample Monitor Tool). Though not shown by this particular autocorrelation diagram, consideration of all beta autocorrelations provides an idea of which draws should be retained (or thinned) for further analysis, in order to minimize autocorrelation and achieve a more concrete assumption of identical, independent draws (i.i.d.), which is a concern for Markov Chains and a central concern of statistics in general. To do this, consider all autocorrelation diagrams simultaneously and select a lag with minimization of autocorrelation across the diagrams.

Alternate model assessment can also be done. They were not explored fully within the scope of this research. Steps 20 and 21 briefly mention each further assessment option.

20. On the "Summary Monitor Tool" click on buttons of interest in turn:
    a. The "stats" button shows a subset of what the "stats" button from the "Sample Monitor Tool" displays, namely the mean and standard deviation.
    b. The "means" button shows the mean for each beta in comma-delimited format.
21. Within the "Correlation Tool" dialog, enter betas of interest in the two node text input boxes (e.g., beta0 and beta01). Then click on the "scatter" button. This will display a Bivariate Posterior Correlation scatter plot of the betas of interest (e.g., beta01s vs. the beta0s).

Final Model

Running the final model also includes several steps. These steps can be categorized into the same four groups: model specification, inference sampling, model updates, and model assessment.

Model specification

1. Choose "Open…" from the "File" menu. Choose the file that contains the final model. The BUGS code window opens with the code representing the model, data, and initial values.
2. Choose "Specification…" from the "Model" menu. The "Specification Tool" dialog opens, as shown in Figure J1.
3. Within the BUGS code window, double click on the word "model" within code. The word "model" should become highlighted.
4. Click on the "check model" button within the "Specification Tool" dialog. The "load data" and "compile" buttons become enabled, as shown in Figure B2. BUGS Model Specification Tool – Check Model.
5. Within the BUGS code window, double click on the word "list" that indicates the beginning of the data section. The word "list" should become highlighted.

6. Click the "load data" button within the "Specification Tool" dialog. Then change the "num of chains" (i.e., number of chains) to the number of chains desired (e.g., from "1" to "4"), as shown in Figure J18.

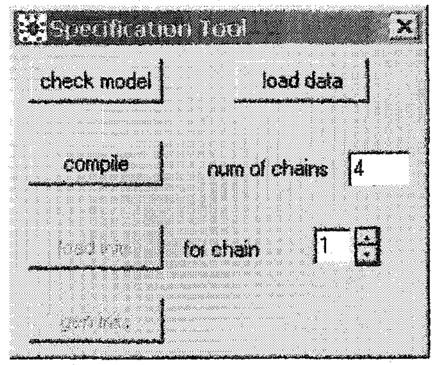


Figure J18. BUGS final model specification – number of chains

Click the "compile" button within the "Specification Tool" dialog. The "load data" and "compile" button become disabled. The "load inits" and "gen inits" buttons become enabled, as shown in Figure J19.

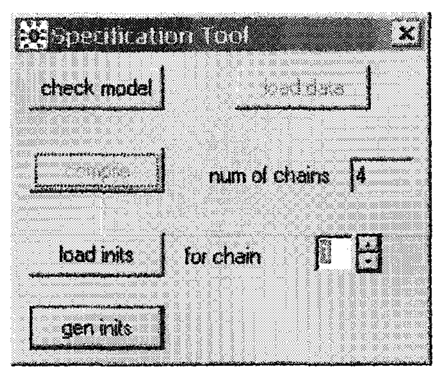


Figure J19. BUGS final model specification tool – compile

7. Scroll down within the BUGS code window to the initial value lists. Within the BUGS code window, double click on the word "list" that indicates the beginning of the first initial values section.
8. Click the "load inits" button within the "Specification Tool" dialog. The "for chain" value iterates to the next chain (e.g., from "1" to "2"), as shown in Figure J20.

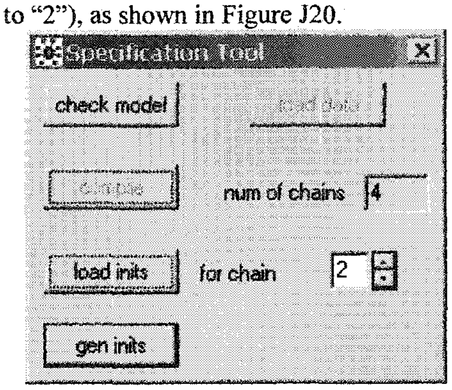


Figure J20. BUGS final model specification tool – initial value specification

9. To load the initial values for the other chains, iterate through step 7, double-clicking on the appropriate "list" for each chain's initial values. Looking at the log, which is displayed by selecting "Open Log" from the "Info" menu, as displayed in Figure J21, the model is initialized after each chain has initial values declared but the log continues to indicate uninitialized chains until this condition is met.

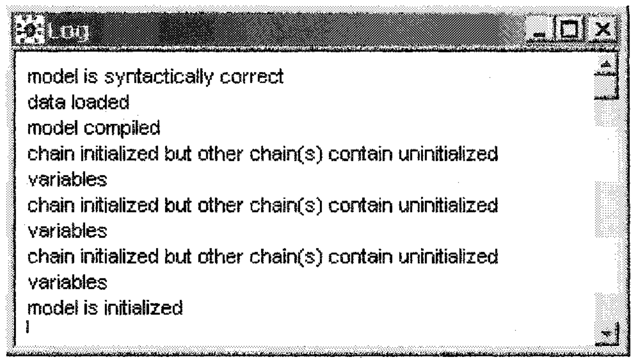


Figure J21. BUGS final model – log

Inference sampling

10. Choose "Samples…" from the "Inference" menu. The "Sample Monitor Tool" dialog opens, as shown in Figure B5. BUGS Sample Monitor Tool.
11. Type in each "beta" value (e.g., beta0, beta01, beta02, ..., beta21) into the "node" text insert box of the "Sample Monitor Tool" dialog, clicking on the "set" button (which will become enabled after each valid "beta" value entry) after each "beta" value entry, as shown in Figure B6. BUGS Sample Monitor Tool – Beta Entry. The previously entered "beta" values can be viewed by using the pull-down option to the right of the text insert box.
12. Once each "beta" value has been entered, type "*" (asterisk) into the "node" text insert box of the "Sample Monitor Tool" dialog. The "*" (asterisk) indicates that all values have been selected for further analysis. The "clear", "trace", "history", "density", "stats", "coda", "quantiles", "GR diag", and "autoC" buttons within the "Sample Monitor Tool" dialog become enabled, as shown in Figure J8. At this point, clicking on any of these buttons would provide no information as the model has not been "updated".
13. From the sample model autocorrelation diagrams an indication of draws to keep (or thin) was obtained. To reflect this in the final model and to limit the draws retained to meet the assumption of i.i.d., set the "thin" value to that previously determined draw rate (e.g., enter "40" if every 40 draws should be retained), as shown in Figure J22.

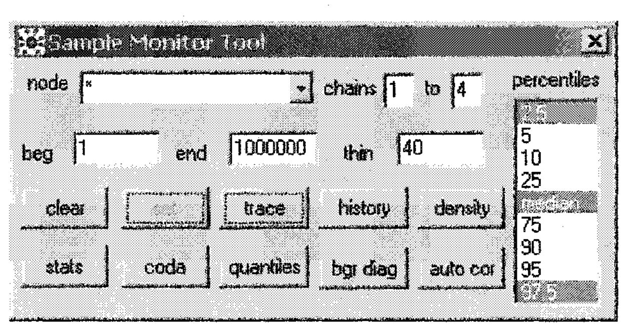


Figure J22. BUGS sample monitor tool – final model thinning specification

14. Additionally, to avoid sampling from the model during "burn-in" (i.e., the time during which the model is converging), specify the "beg" value to a sufficiently high number to assure avoidance (e.g., 2000). An "end" value may also be set (e.g., 30,000). Figure J23 displays these settings.

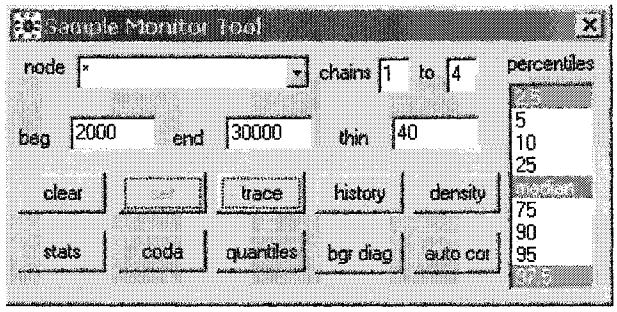


Figure J23. BUGS sample monitor tool – final model beginning/end specification

Note that the Sample Monitor Tool, for this multiple chain model, allows specification of which chains to monitor. Also, be aware that the specifications of "thin", "beg", and "end" influence the draws that are retained and displayed when requesting coda by selecting the "coda" button after updates have been run.

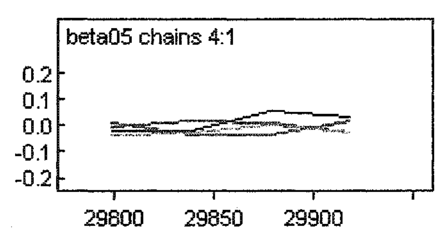
Model updates

15. Choose "Update…" from the "Model" menu. The "Update Tool" dialog opens, as shown in Figure B8. Update Tool. Initially, the "Update Tool" dialog indicates 1000 updates, with a refresh of 100. Set the updates at a reasonable level (e.g., 30000) that will ensure both a sufficient amount of "burn-in" time and a sufficient amount of results for further sampling and analysis.

For the final model "thin", "beg", and "end" values specified, the "burn-in" is considered the first 2,000 draws and the sample that draws are selected from is 28,000 (i.e., 30,000 – 2,000). Based on the "thin" rate of "40", this results in 700 (i.e., 28,000/40) draws for each beta for each chain and a total of 2,800 (700 * 40) draws for each beta across all chains. This is a reasonable sample on which to base statistical analyses.
16. Click on the "update" button of the "Update Tool" dialog. Wait for the update run to finish. Progress is indicated in the "iteration" display text box.

Model assessment

17. On the "Sample Monitor Tool" click on buttons of interest in turn:
    a. The "trace" button for multiple chains shows the time series of the beta draws for each chain (indicated by color) as updates progress, but only the last 200 draws. A sample trace output from the final model is shown in Figure J24.



J24. Final model - sample trace diagram

b. The "history" button for multiple chains shows the time series of the beta draws for each chain (indicated by color) over all updates, which helps in determining model convergence within and between chains. A sample history output from the final model is shown in Figure J25.

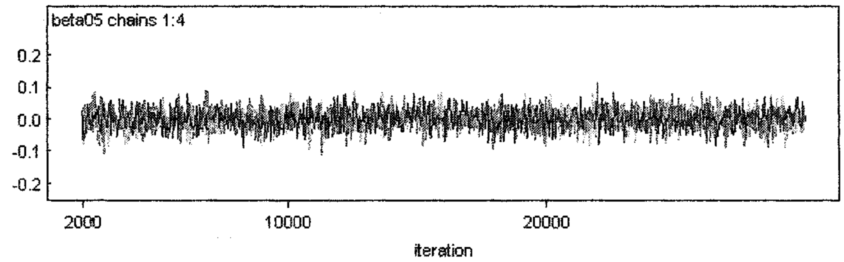


Figure J25. Final model - sample history diagram

c. The "density" button for multiple chains displays the posterior distribution of the betas as a single density across all chains, as indicated in Figure J26.

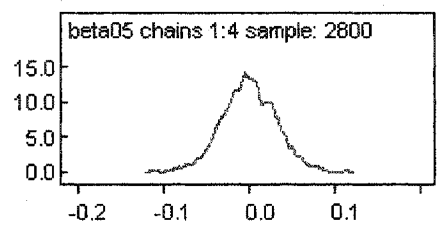


Figure J26. Final model – sample density diagram

The density for this beta, because it is centered near zero, indicates that no information can be gained about dependent variable effects from this covariate.

d. The "stats" button for multiple chains shows the statistics for each beta as a single line of statistics across all chains.

e. The "coda" button displays two windows: a "coda index" window and a "coda" window. The "coda index" window for multiple chains shows the relative location for the draws related to each "beta" within the "coda" window for each chain. For multiple chains, multiple "coda" windows are displayed, one for each chain. Each "coda" window contains draws from each update for each "beta".

f. The "quantiles" button for multiple chains graphically displays the running quantiles for all draws for each chain (indicated by color). This running quantile graphic displays the relative stability of the updates across all chains, which helps in determining model convergence within and between chains. A sample quantiles output from the final model is shown in Figure J27.

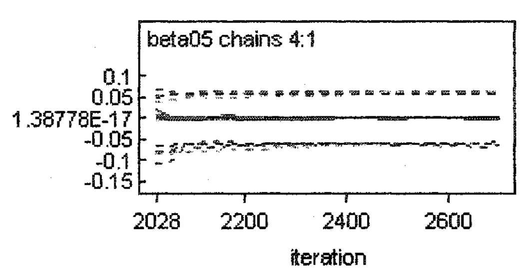


Figure J27. Final model - sample quantiles output

g. The "bgr" button for multiple chains graphically displays the Gelman-Rubin statistic for all draws for each chain (indicated by color). The Gelman-Rubin statistic graphic helps in visualization of multi-chain convergence, both within and between chains. A sample Gelman-Rubin statistic graphic is shown in Figure J28.

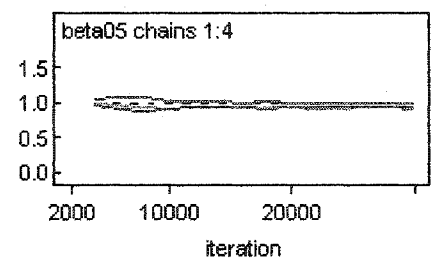


Figure J28. Final model – sample Gelman-Rubin statistic

At least for the beta depicted in this graphic the chains appear to have converged.

h. The "autoC" button for multiple chains displays the autocorrelation for each beta for each chain (indicated by color). A sample autocorrelation output from the final model is shown in Figure J29.

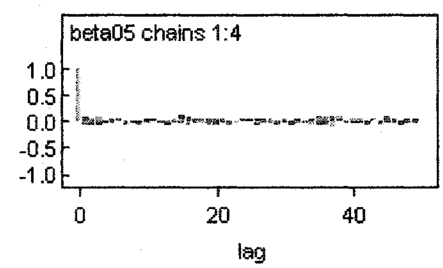


Figure J29. Final model - sample autocorrelation output

If thinning was utilized, the autocorrelation output for each beta should show all autocorrelations minimized, as this graphic does.

APPENDIX K. LIST OF ABBREVIATIONS/ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials
ACC – Asphalt Cement Concrete
B/C – Benefit-Cost Ratio
BUGS – Bayesian Using Gibbs Sampling (software)
CART – Classification and Regression Trees (CART)
CDC – Centers for Disease Control
CHSIM – Comprehensive Highway Safety Improvement Model (SafetyAnalyst)
CI – Confidence Interval
CMF – Crash Modification Factor
DEV – Daily Entering Vehicles
EB – Empirical Bayesian
FHWA – Federal Highway Administration
GENMOD – Generalized Linear Model procedure with SAS
GIMS – Geographic Information Management System (Iowa)
GIS – Geographic Information Systems
GLIM – Generalized Linear Models
GLMM – Generalized Linear Mixed Model
GR – Gelman-Rubin (BUGS)
HCM – Highway Capacity Manual
HEP – Hazard Elimination Program
HES – Hazard Elimination Systems
HRB – Highway Research Board (e.g., Iowa HRB)
HRGreen – Howard R. Green Company
HSIP – Highway Safety Improvement Program
HSIS – Highway Safety Information System
HSM – Highway Safety Manual
ID – Identification Number
I.I.D. – Independent and Identically Distributed
IHSDM – Interactive Highway Safety Design Model
IIHS – Insurance Institute for Highway Safety
Iowa DOT – Iowa Department of Transportation
ITE – Institute of Transportation Engineers
LRM – Linear Reference Method
LRS – Linear Referencing System
MADD – Mothers Against Drunk Driving
MCMC – Markov Chain-Monte Carlo
MEV – Million Entering Vehicles
MLE – Maximum Likelihood Estimator
MPH – Miles Per Hour
MRI – Midwest Transportation Institute
MVD – Motor Vehicle Division (e.g. Iowa DOT MVD)
NB – Negative Binomial
NCHRP – National Cooperative Highway Research Program
NHTSA – National Highway Traffic Safety Administration
NRC – National Research Council
NSC – National Safety Council
OLS – Ordinary Least Squares

PCC – Portland Cement Concrete
PSA – Public Service Announcements
RADD – Recording Artists, Actors, and Athletes and Drunk Driving
RFP – Request For Proposal
RTM – Regression to the Mean
SADD – Students Against Destructive Decisions
SAS – SAS Institute, Inc. or their Statistical Analysis Software
SAVER – Safety Analysis, Visualization, and Exploration Resource (SAVER)
SEMCOG – SouthEast Michigan Council of Governments
SHSP – Strategic Highway Safety Plan
SICL – Safety Improvement Candidate Location
SMS – Safety Management Systems (e.g., Iowa SMS)
SPF – Safety Performance Function
SWiP – Sites With Promise
TAS – Office of Traffic and Safety (Iowa DOT)
TPM – Transition Probability Matrix
TRB – Transportation Research Board
TSF – Transportation Safety Fund (Iowa DOT)
TSIP – Traffic Safety Improvement Program (Iowa DOT)
US DOT – United States Department of Transportation

APPENDIX L. GLOSSARY OF TERMS

Autocorrelation: The temporal association between observations of a series of observations ordered across time (TRB 2003).

Bayesian philosophy: Bayesian statisticians base statistical inference on a number of philosophical underpinnings that differ in principle to frequentist or classical statistical thought. First, Bayesians believe that research results should reflect updates of past research. In other words, prior knowledge should be incorporated formally into current research to obtain the best 'posterior' or resultant knowledge. Second, Bayesians believe that much can be gained from insightful prior, subjective information as to the likelihood of certain types of events. Third, Bayesians use Bayes' theorem to translate probabilistic statements into degrees of belief, instead of a classical confidence interval interpretation. Bayesian methods essentially introduce (mathematically) subjective prior information into the analysis framework (TRB 2003).

Bayes' theorem: This theorem, developed by Bayes, is a theorem that relates the conditional probability of occurrence of an even to the probabilities of other events. Bayes' theorem is given by:

$$P(A|B) = P(B|A)\,P(A) / [P(B|A)\,P(A) + P(B|A')\,P(A')]$$

where P(A|B) is the probability of even A given that even B has occurred, P(A) is the probability of event A, and P(A') is the probability of event A not occurring. Bayes' theorem can be used to overcome some of the interpretive and philosophical shortcomings of frequentist or classical statistical methods (TRB 2003).

Confidence interval: A confidence interval is a calculated range of values known to contain the true parameter of interest over the average of repeated trials with specific certainty (probability). The correct interpretation of a confidence interval is as follows: If the analyst were to repeatedly draw samples at the same levels of the independent variables and compute the test statistic (mean, regression slope, etc.), then the true population parameter would lie in the $1-\alpha\%$ confidence interval α times out of 100.

Continuous variables: A continuous variable is either measured on the interval or ratio scale. A continuous variable can theoretically take on an infinite number of values within an interval. Examples of continuous variables include measurements in distance, time, and mass (TRB 2003).

Credible set: The Bayesian analogue of a classical confidence interval. It enables direct probability statements about the likelihood of θ falling in the credible set (Carlin and Louis 2000).

Empirical Bayes: A statistical methodology which assumes a priori information about the probability distribution on the true population parameters and estimates these parameters using data (Pendleton 1991).

Generalized linear model (GLIM): An extension of traditional linear models that allows the mean of a population to depend on a linear predictor through a nonlinear link function and allows the response probability distribution to be any member of an exponential family of distributions (SAS Institute 1999).

Gibbs sampling: A special case of signle-component Metropolis-Hastings. Gibbs sampling consists in sampling from full conditional distributions (Gilks et al. 1996).

Goodness-of-fit: Goodness-of-fit describes a class of statistics used to assess the fit of a model to observed data. There are numerous goodness-of-fit measures, including the coefficient of determination R^2, the F-test, the chi-square test for frequency data, and numerous other measures. It should be noted that goodness might refer to the fit of a statistical model to data used for estimation, or data used for validation (TRB 2003).

Hierarchical Bayesian: Bayesian analysis involving several levels that allow each model variable to have a distribution.

Interaction: Two variables X_1 and X_2 are said to interact if the value of X_1 influences the value of X_2 positively or negatively. An interaction is a synergy between two or more variables, and reflects the fact that their combined effect on a response not only depends on the level of the individual variables, but their combined levels as well (TRB 2003).

Likelihood function: The probability or probability density of obtaining a given set of sample values, from a certain population, when this probability or probability density is regarded as a function of the parameter(s) of the population and not as a function of the sample data.

Metropolis-Hastings: An algorithm defining the decision points for a Markov chain. For the Metropolis-Hastings algorithm, at each time t, the next state X_{t+1} is chosen by first sampling a candidate point Y from a proposal distribution $q(.|X_t)$ (Gilks et al. 1996).

Negative binomial: The resulting discrete probability distribution of a Poisson distributed random variable, accident counts, given the gamma prior distribution hyperparameters (Pendleton 1991).

Nominal variables: A variable measured on a nominal scale is the same as a categorical variable. The nominal scale lacks order and does not possess even intervals between levels of the variable. An example of a nominal scale variable is Vehicle Type, where levels of response include truck, van, and auto. The nominal scale variable provides the statistician with the least amount of information relative to other scales of measurement (TRB 2003).

Ordinal variables: The ordinal scale of measurement occurs when a random variable can take on ordered values, but there is not an even interval between levels of the variable. Examples of ordinal variables include the choice between three automobile brands, where the response is highly desirable, desirable, and lease desirable. Ordinal variables provide the second lowest amount of information compared to other scales of measurement (TRB 2003).

Poisson: The Poisson distribution is often referred to as the distribution of rare events. It is typically used to describe the probability of occurrence of an event over time, space, or length. In general, the Poisson distribution is appropriate when the following conditions hold: the probability of 'success' in any given trial is relatively small; the number of trials is large; and the trials are independent. The probability density function for the Poisson distribution is given as:

$$\Pr(X=x) = p(x,\lambda) = \lambda^x e^{-\lambda} / x!, \text{ for } x = 1, 2, 3, \ldots, \infty$$

where, x is the number of occurrences per interval, 1 is the mean number of occurrences per interval, a is the mean rate of occurrence (occurrence per unit time, length, or space), DT is the interval length, and 1 = a DT (TRB 2003).

Posterior distribution: The distribution that all inference concerning θ is made in Bayesian analysis. The posterior distribution is defined by Bayes' theorem.

Prior distribution: The probability distribution on the true population parameters – in this case, the gamma distribution of the true site mean accident rates, λ_i (Pendleton 1991).

Regression-to-the-mean (RTM): The phenomenon where the observed value will shrink toward the population's true mean during the post treatment period independent of treatment (Pendleton 1991).

Safety performance functions (SPFs): Functions that describe the safety performance of a category of sites.

Transition probability matrix (TPM): A matrix containing the probabilities and expectations for a Markov chain.

APPENDIX M. LIST OF WEBSITES

Automobile

American Automobile Association (AAA) – http://www.aaa.com/

Citizen Advocacy Groups

Advocates for Highway and Auto Safety – http://www.saferoads.org/

American Association of Retired People (AARP) – http://www.aarp.org/

Citizens Against Speeding and Aggressive Driving (CASAD) – http://www.aggressivedriving.org/

Citizens for Reliable and Safe Highways (CRASH) – http://www.trucksafety.org/

Mothers Against Drunk Driving (MADD) – http://www.madd.org/

Network of Employers for Traffic Safety (NETS) – http://www.trafficsafety.org/

Parents Against Tired Truckers – http://www.patt.org/

Record Artists, Actors, & Athletes Against Drunk Driving (RADD) – http://www.radd.org/

Students Against Destructive Decisions/Students Against Driving Drunk (SADD) - http://www.saddonline.com/

The National Campaign to Stop Red Light Running – http://www.stopredlightrunning.com/

Underride Network – http://www.underridenetwork.org/

Commercial Vehicle

American Trucking Association (ATA) – http://www.trucking.org/

Commercial Vehicle Safety Alliance (CVSA) – http://www.cvsa.org/

Highway Angels – http://www.truckload.org/highwayangels/

National Motor Truck Association
- Indiana – http://www.imtaonline.net/
- New Jersey – http://www.njmta.com/
- West Virginia – http://www.wvmotortruck.org/

National Private Truck Council (NPTC) – http://www.nptc.org/

Owner-Operator Independent Drivers Association (OOIDA) – http://ooida.com/

Truckload Carriers Association – http://www.truckload.org/

United Highway Carriers Associations (UHCA) – http://www.uhca.com/

Federal

BTS website – http://www.btw.gov/

FHWA website – http://www.fhwa.dot.gov/

FMCSA website – http://www.fmcsa.dot.gov/

FRA website – http://www.fra.dot.gov/

FTA website – http://www.fta.dot.gov/

NHTSA website – http://www.nhtsa.dot.gov/

RSPA website – http://www.rspa.dot.gov/

STB website – http://www.stb.dot.gov/

TFHRC website – http://www.tfhrc.gov/

TRB website – http://gulliver.trb.org/

US DOT website – http://www.dot.gov/

Insurance

Insurance Information Institute (III) – http://www.iii.org/

Insurance Institute for Highway Safety (IIHS)/Highway Loss Data Institute (HLDI) – http://www.hwysafety.org/

National Council on Compensation Insurance – http://www.ncci.org/

Iowa

Iowa DOT website – http://www.dot.state.ia.us/

National Model website – http://www.dot.state.ia.us/natmodel/

ODS website – http://www.dot.state.ia.us/mvd/ods/

SAVER website – http://www.dot.state.ia.us/crashanalysis/savermain.htm

SMS website – http://www.iowasms.org/

TAS website – http://www.dot.state.ia.us/traffic/

National (government and professional)

American Association of Motor Vehicle Administrators (AAMVA) – http://www.aamva.org/

American Association of State Highway and Transportation Officials (AASHTO) – http://www.aashto.org/

American Association of Motor Vehicle Administrators (AAMVA) – http://www.aamva.net/

American Society of Civil Engineers (ASCE) – http://www.asce.org/

Association of Metropolitan Planning Organizations (AMPO) – http://www.ampo.org/

Governor's Highway Safety Association (GHSA) (formerly National Association of Governor's Highway Safety Representatives (NAGHSR)) – http://www.naghsr.org/

Institute of Transportation Engineers (ITE) – http://www.ite.org/

National Association of Counties (NACo) – http://www.naco.org/

National Association of Regional Councils (NARC) – http://www.narc.org/

National Governor's Association (NGA) – http://www.nga.org/

National Safety Council (NSC) → Association of Traffic Safety Information Professionals (ATSIP) → (sponsor International Traffic Records Forum annually) – http://www.nsc.org/

National Sleep Foundation (NSF) - http://www.sleepfoundation.org/

Society of Automotive Engineers (SAE) – http://www.sae.org/

Researchers

Center for Transportation Research and Education (CTRE) – http://www.ctre.iastate.edu/

Midwest Research Institute – http://www.mriresearch.org/

University of North Carolina, Chapel Hill, Highway Safety Research Center (HSRC) – http://www.hsrc.unc.edu/

Transit

American Bus Association (ABA) – http://www.buses.org/

American Public Transportation Association (APTA) – http://www.apta.com/

United Motorcoach Association (UMA) – http://www.uma.org/

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