

The development of a case based reasoning tool for high-speed signalized expressway intersections in the State of Iowa

by

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**Abstract**

The safety of signalized expressway intersections has been the focus of prior research. These efforts have yielded results that were either inconclusive or required further investigation. This thesis presents the application of case-based reasoning to the issue. Similar intersections and crash reduction factors (CRFs) are used to establish expected crash performance for a candidate intersection. A spreadsheet based tool is developed that compares candidate intersections to these comparison sites. The tool uses expert opinions, attribute weights, and crash reduction factors to assist in the decision to signalize a site, to compare performance of existing signalized intersections to similar sites, or to explore the potential safety effects of intersection modification or changes in traffic patterns.

## **Chapter 1 Introduction**

### **1.1. Introduction**

Engineering practices are continually evolving. Lessons are learned from both research and informal “experiments” in practice, and experience adds to the academic foundation of the engineer. At times, an engineer is faced with making decisions with imperfect or incomplete information. Books, manuals, and reports may be consulted as an aid to the engineer, however, for some situations, the body of literature is incomplete or missing altogether. The safety effectiveness of signaling high-speed expressway intersections is one such situation.

Where data are incomplete, or previous studies conflict as to the effectiveness of a particular engineering treatment, expert opinions may be quite helpful, especially to engineers with less experience with signals on high speed facilities. The development of a system that uses these opinions as well as historical data for signalized high-speed expressway intersections is the subject of this thesis.

The Federal Highway Administration (FHWA), American Association of State Highway Transportation Officials (AASHTO), and the Iowa Department of Transportation (IaDOT) have as a common goal, to improve the safety of the nation’s roadways. This goal may be achieved by reducing the number of fatality and injury crashes, as well as the severity and morbidity resulting from these crashes.

A common location for fatal or injury crashes is the intersection of two or more roadways. According to FHWA statistics, approximately 45 percent of all injury crashes and 20 percent of all fatalities nationwide occur in intersection-related crashes. (FHWA: Intersection Safety)

FHWA specifically has established its goal of a 20 percent reduction in the number of road-related injuries and fatalities by the year 2008. (FHWA: Intersection Safety) AASHTO developed a *Strategic Highway Safety Plan* to supplement the efforts of the FHWA. The plan has established “Improving the Design and Operation of Highway Intersections” as one its 22 plan goals. (AASHTO, 2005)

The probability of an intersection crash involving a fatality or injury increases as the speed of the vehicles involved increase. High-speed expressway intersections are therefore the focus of this study. Previous studies of these intersections in Iowa have been inconclusive from a statistical point of view. However, the data studied in these previous projects may still be very useful to decision-makers if provided in a useful way.

The Manual on Uniform Traffic Control Device (MUTCD) is considered the primary source for traffic control standards. The MUTCD, using warrants for the implementation of signalized traffic control, provides an engineer with an initial screening device for the selection of signalized traffic control. One of the MUTCD warrants is the “safety warrant” that is based

on the number of crashes occurring at an intersection during a specific time period. If the MUTCD safety warrant is satisfied, it is suggested that an engineering study be completed to further analyze the benefit of signal installation. (MUTCD, 2003) A system based on past performance of similar high-speed expressway intersections can facilitate such studies.

This thesis reports on a project which is the third in a series of studies of signalized high-speed expressway intersections. The first two phases focused on before and after performance of signalized high-speed expressway intersections located in the State of Iowa. Results of the prior research indicated “mixed” conclusions on the safety effects of expressway intersection signalization. (Knox, 2005) The latest phase of research utilizes expert opinions and case-based reasoning departing from the statistical techniques attempted in the first two phases.

An expert focus group was conducted to discuss the previous research, and identify direction of the current research. Several research ideas were discussed, including large scale studies that are unfortunately beyond the resources of the present research. It was suggested during the focus group that an expert systems or decision-tree methodology might be beneficial. The focus of this thesis, therefore, is the development of a decision-support system based on transportation safety expert opinions, and a database of some 135 existing high speed expressway signals in the State of Iowa.

## **1.2. Background**

An expressway is “a divided highway facility usually having two or more lanes for the exclusive use of traffic in each direction and partial control access”. (Iowa DOT Glossary) Expressways differ from freeways or interstates in the levels of access (expressways can have at-

grade access at intersections). The definition of “high-speed” varies from 35 to 55 miles per hour. (Mueller, 2007; Gibby, 1992; Knox, 2005) “High-speed”, as used in this report means, intersections with major road speed limit of 45 miles per hour or greater.

One-third of all fatal intersection crashes occur at a signalized intersection. (AASHTO, 2005) Therefore, a large reduction in fatalities is theoretically possible by improving the safety of such intersections. The increasing number of crashes at intersections, as well as the rapidly increasing extent of expressways themselves, has led to more interest and research on this potential topic.

Study intersections are located on divided roadways with four or more lanes of through traffic, and a major road speed limit of 45 miles per hour or greater. Signalized interchange termini that intersect with expressways are also included. The major roadways must also satisfy IaDOT database or AASHTO “Green Book” expressway classifications. (AASHTO, 2004)

Study intersections were identified by one or more of three methods: examination of previous studies, personal knowledge of locations, or query of the IaDOT’s roadway Geographical Information Management System (GIMS) roadway system database. Previous studies were used to identify the majority of the intersections. (Knox, 2005) Using Arc View Geographic Information System (GIS), a GIMS query identified several additional intersections. The Appendix lists the query statement including explanations of field (attribute) names and values. The intersection locations were verified using aerial images and in some cases, visits to the intersection locations

A complete study of all the high-speed signalized expressway intersections in the State of Iowa was desired by the project sponsors. However, one or more high-speed intersections may not have been identified due to limitations of the selection methodology.

### **1.3. Problem Statement**

Sometimes, signals are used as traffic safety measures. At low speed, high volume locations, the safety effectiveness of signals is more or less undisputed. However, previous research has indicated that at high speed locations, safety effectiveness is “mixed” at best. (Knox, 2005) Previous research has proposed statistical models which require more data to produce significant results. While the data available for prior research may not have been sufficient to support statistical models, it was desired to develop a tool that could help engineers make use of the information available as well as the opinions of safety experts. Therefore, this thesis mines engineering experience, crash history, and previous research to develop a case-based reasoning tool to assist in making the determination of the safety effectiveness of a proposed high-speed signal.

Whether to signalize a high-speed intersection is not a simple choice. While signals may serve to reduce right angle crashes, they may also induce other types and severities of crashes, including rear-ends. Because signals may have both positive and negative safety effects, it is desirable to provide the decision-maker with as much information as possible as to the potential operation of the signal. The decision-maker may find it beneficial to examine the safety performance of signals located at “similar” intersections. Defining “similar” however, presents a challenge to the present work.

Using an expert panel and recent crash data, this thesis presents a “case-based reasoning” approach as a decision-support tool. A spreadsheet based tool is developed to implement the approach. The spreadsheet is easy to use and may be modified by the user to incorporate additional case data, or to change parameters that affect the definition of “similarity” which in turn compares a candidate intersection to comparable sites. Summary statistics and graphs enable visualization of anticipated safety performance.



## **Chapter 2 Review of Literature**

### **2.1. Introduction**

The safety performance of a signalized expressway intersection depends on a combination of several factors. The factors include traffic and human characteristics, intersection attributes, and intersection design elements. Unfortunately, from a statistical analysis perspective, very few intersections have the exact same features, attributes, or characteristics. Therefore, artificial intelligence/expert systems, or more specifically, case-based reasoning approaches, are explored in this research.

It is important that engineers understand the safety effects of features before constructing or modifying an intersection. Fortunately, literature does exist that may be helpful in developing this understanding. Therefore, previous studies of high-speed, expressway, and signalized intersections are reviewed herein.

This review is divided into four sections: crash data, expressway and signalized intersection safety research, intersection feature (attributes) safety-related research, and artificial intelligence systems applications.

### **2.2. Crash Data**

The proper selection of crashes is an important component of any highway safety project. Selection of crashes which “belong” to an intersection can be more complicated than would seem. For example, crash locations may not be precisely known. Further, spatial queries of proximate crashes may result in much different selected sets of crashes than say, would attribute-

based queries. Also, various spatial buffers may be specified. Finally, the relevance of an intersection to a particular crash may well depend on the traffic conditions and queues at the time of the crash. For the latter, it is rare that data would exist to facilitate this type of determination.

Jackson (2006) attempted to determine the most accurate method of selecting crashes for an intersection. He indicated that most research does “little to state the methodology of how crashes were assigned to a location”. Jackson concluded that a combined selection process of spatial proximity to an intersection and crash attributes would provide the most relevant results.

Crash data may vary in attribution and for some geographical areas, may have been collected using different recording forms or thresholds. (Preston, 2004; Jackson, 2006) Combining crash data from different jurisdictions can be problematic. Fortunately for this research, a standardized data set was available for all reporting jurisdictions within the State of Iowa.

Knox (2005) conducted research on the safety performance of signalizing expressway intersections in Iowa. He compared analyses selecting crashes using 500 feet and 150 feet radius circular buffers, concluding that 150 feet buffers produced better results. IaDOT staff recommends using 75 feet buffers for selecting crashes at urban locations and 150 feet for rural locations. (Jackson, 2006) The larger radius for rural sections is recommended due to higher speeds and lower driveway densities.

As mentioned, intersection crashes may be selected spatially or by specifying certain crash attributes. In addition to spatial buffering, Knox (2005) used crash roadway type (intersection) to select intersection crashes. Knox then assigned each crash a qualitative score to

indicate the likelihood a crash was intersection-related. Jackson (2006) concluded that selecting crashes based on spatial proximity with further consideration of roadway type, major cause, and vehicular action further refined the process of selecting intersection-related crashes.

## **2.3. Signalized Expressway Intersections**

### **2.3.1. Benefits of an Expressway**

To address safety and operational limitations of two-lane roads, many miles are converted into divided expressways. Expressways provide some of the benefits of freeways, but at much lower construction costs due to the provision of limited at-grade access. (Maze et. al., 2005)

The AASHTO “Green Book” considers the construction of an expressway “to increase the safety, comfort, and ease of operation”. (AASHTO, 2004) Several advantages are realized in terms of travel time, operations, and safety because of the speeds and design of expressways. Expressways typically have medians that accommodate left turn lanes and two-stage turning movements. The addition of a median with a turn lane results in fewer head-on and rear-end crashes. (AASHTO, 2004)

### **2.3.2. Expressway Safety**

Knox (2005) evaluated the signalization of expressway intersections in Iowa using cross-classification, matched (yoked) paired, before-and-after, and empirical bayes analysis techniques. He concluded various results from his research. Cross-classification indicated that signalized intersections have an increased number of crashes (as opposed to two-way stop

control), but before-and-after analysis indicated that signalization reduced the crash rate. Knox himself classified the results as “mixed”, and suggested that the small sample size of the study resulted in statistically insignificant results. (Knox, 2005) Perhaps this is not surprising, as Persaud (1988) suggests that cross-section and before-and-after studies will often have different results.

In a study of expressway intersections in Iowa and Minnesota, Maze showed that as traffic volume of expressways increases, the crash rate and severity also increase. He concluded that while the benefit of expressway intersection signalization is unknown, it is accepted that frequency of various crash types does change. (Maze, 2004)

Persaud (1988) investigated the relationship between signalization and safety. He discusses previous before-and-after traffic signal safety studies and further examined their conclusions. He determined that the methods or practices used to form the conclusions of the prior research were “impractical” and did not provide any consensus on the safety affects of signalizing an intersection. Persaud noted the apparent lack of understanding of the regression-to-the-mean phenomena as a reason prior research concluded that traffic signals may increase the safety performance of an intersection. He suggested that future research should understand the factors that caused the safety change before making a conclusion on the safety effects of signalization. Persaud suggested creating a tool to “quantify the likely safety impact of a contemplated installation based on various installation circumstances”. (Persaud, 1988)

### **2.3.3. Two-Way Stop-Controlled Expressway Intersections**

Two-way stop-control is the most common control type for intersections along expressways. This type of control is prevalent at most low-volume local road intersections. A study completed in Nebraska concluded that, under the same conditions, stop-controlled intersections had more accidents per year than signalized intersections or interchanges. The research included development of benefit-cost ratios for each intersection improvement (signal or interchange). (Bonneson, 1992)

Horizontal and vertical curvature at stop-controlled intersections was examined by Maze et. al. (2006). In this study, eight of the ten worst performing stop-controlled intersections had either intersection skewness of 15 degrees or more, horizontal curvature of three degrees per 100 feet, or vertical curvature of four percent or more. The same study analyzed the safety performance of two-way stop-controlled expressway intersections at various traffic volume levels. The study concluded that, as traffic volumes increased, the crash rate, crash severity rate, and fatal crash rate also increased. The report also concluded that “intersection crash density increases with increasing major road volume and crash rate increases with increasing minor road volume”. (Maze, 2006)

Crash type and location at two-way stop-controlled intersections were examined by Hochstein et al. The research concluded that far-side right-angle collisions reduce the safety benefit of expressways. These crashes are typically caused by improper gap selection, vehicles

attempting to make one-stage turning or crossing movements, whereas two-stage movements would likely be safer. Hochstein concluded that improper gap selection and crossing movements by the minor roadway traffic were more of an issue than intersection recognition. (Hochstein et. al., 2007)

Previous research on two-way stop-controlled intersections has identified several factors related to poor safety performance. However, remedies for these factors have not been fully implemented and are sometimes not well understood. The focus of the research presented in this thesis is to provide a decision-support tool that captures some of the experience of previous performance and makes it available to engineers considering the signalization of a presently stop-controlled intersection.

#### **2.3.4. Signalization**

Signalization is often viewed as an operations and safety treatment. The Manual of Uniform Traffic Control Devices (MUTCD) is the chief reference for implementation of traffic control devices in the United States. However, the MUTCD is not intended to replace engineering judgment, but rather to supplement the decisions made by engineers. According to the MUTCD, many engineers view traffic control as a “panacea” for all traffic problems at an intersection. This has led to intersections being signalized for various reasons beyond strictly meeting MUTCD warrants. However, the MUTCD itself suggests that engineering studies be conducted even if one or more signal warrants are met. (MUTCD, 2003)

The installation of traffic signals changes the type and location of crashes at an intersection. In a study using Colorado data, angle crashes were generally reduced, but rear-end crashes were often increased, while the total number of crashes generally increased as a result of signalization. (Sarchet, 2005) Institute of Transportation Engineers *Manual of Traffic Signal Design* also reports that increase in the frequency of collisions can result from improper or unwarranted signal installation. (ITE, 2001) Sarchet's research concluded that even though the intersection parameters may satisfy signal warrants, the total number of crashes may increase by as much as 75 percent. He concluded that installing a traffic signal is "not likely to improve safety".

Khattak (2006) concluded that no statistical difference in total crashes was indicated when comparing signalized and unsignalized intersections. In a study using Iowa data, Thomas (2001) concluded that installing traffic signals with left turn lanes had the best benefit-cost ratio for a group of intersection improvement projects in Iowa. However, he cautioned that his analysis did not account for the potential effect of regression-to-the-mean.

### **2.3.5. Traffic Signal Warrants**

The MUTCD provides a list of eight traffic signal installation warrants to be considered by the engineer prior to implementation. A warrant is defined as "a threshold condition that, if found to be satisfied as part of an engineering study, shall result in an analysis of other traffic conditions or factors to determine whether a traffic control signal or other improvement is justified". (MUTCD, 2003)

Warrants are based on traffic volume, crash experience, school crossings, coordinated systems, and the roadway network. The installation of a traffic signal is not completely justified by the satisfaction of one the MUTCD warrants and are only a minimum threshold for installing a traffic signal. The MUTCD suggests that an engineering study be completed regardless of the satisfaction of the warrants. It goes on to say that any decision to use a particular traffic control device should be based on sound engineering judgment. The MUTCD also states that the warrants are only a minimum threshold for installing a traffic signal. (MUTCD, 2003) National Cooperative Highway Research Program (NCHRP) Report 491 states, “it is cautioned that satisfying a traffic signal warrant shall not in itself mean the installation of a traffic control signal is required”. (McGee, 2003)

The application of the crash warrant is intended for situations “where the severity and frequency of crashes are the principal reasons to consider installing a traffic control signal”. (MUTCD 2003) However, for expressways in particular, simply meeting MUTCD signal warrants does not mean that a signal is the only or even the best safety strategy.

Wainwright (2004) discusses going beyond the minimum suggested in the MUTCD. The paper states, “that meeting the minimum requirements of the MUTCD is not enough”. Wainwright suggests that agencies should satisfy beyond the minimum requirements because of the reduction in intersection-related crashes, and the increased operational efficiency that may be achieved. The Wainwright paper concludes by encouraging agencies to implement beyond the minimum requirements on either a case-by-case method or agency wide consideration. (Wainwright, 2004)



MUTCD warrant number seven relates to crash experience. It states that if “five or more reported crashes, of types susceptible to correction by traffic control signal, have occurred within a 12-month period” the warrant is satisfied. (MUTCD, 2003) Warrant seven does not, however, indicate the types or severity of crashes that would be mitigated by installing a signal. Nor does it caution the user to consider potential effects of regression-to-the-mean. NCHRP Report 491 discusses the implications of not addressing regression-to-the-mean when establishing crash totals as a method of determining the installation of a traffic signal. (McGee, 2003)

## **2.4. Improving Expressway Intersection Safety Performance**

### **2.4.1. State Experiences**

According to a study Bonneson et al, most states build rural expressways with at-grade intersections. The study found that most states consider signalization or signing improvements at high-crash locations. From a survey of states, the report found that 30 percent of responding states make the decision to signalize intersections based solely on traffic volumes while 52 percent use a combination of accident rates and traffic volumes. About 30 percent of the surveyed states do not signalized expressway intersections unless alternative measures have not succeeded. (Bonneson, 1993)

### **2.4.2. Intersection Safety Improvements**

The safety of an intersection can be improved by the application of several safety mitigation strategies. The AASHTO “Green Book” indicates that more conflict points lead to the potential for more crashes, and suggests eliminating as many of these points as possible at the

problem intersections. The “Green Book” also states, “regardless of design, signing, and signalization, at-grade intersections have a potential for crashes resulting from vehicle-vehicle conflicts”. (AASHTO, 2004)

Suggestions for treatments for expressway intersections with poor safety performance are provided by Hochstein and Preston. Hochstein (2007) suggests converting the intersection type to either T, an offset T, or providing a J-turn. In addition, he suggests closing low volume minor roads and providing access via a frontage road, widening medians, and/or signing median crossing movements to encourage two-stage crossing maneuvers. Preston (2004) suggests making minor geometric improvements to a poorly performing intersection before considering signalization or an interchange.

### **2.4.3. Safety Effect of Driver and Vehicle Characteristics**

Various human and vehicle mix factors may affect the safety performance of a signalized expressway intersection. The following sections discuss some of these factors.

#### **2.4.3.1. Driver Age**

Bao et al studied the reaction times and stopping performance for three age ranges for stop-controlled expressway intersections. The study concluded that younger drivers had the fastest reaction time, but were the least likely age group to come to a complete stop. Younger drivers were considered the age group to take the most risky chances at an intersection. (Bao, 2007) Hochstein also concluded that the age of a driver has an effect on a gap selection at expressway intersections. (Hochstein, 2007) Mueller et al researched the impacts of left-turn

phasing on older and younger drivers at high-speed signalized intersections. They reported that for all types of phasing, older drivers had a higher crash rate than middle- or younger-aged drivers. The highest crash rate for a specific left-turn phase was the protected-permitted phase. (Mueller, 2007)

#### **2.4.3.2. Turning Movements**

Hochstein determined that offset right-turn lanes may reduce the number of crashes at an unsignalized expressway intersection by providing better sight distance (and hence, better gap selection) for minor road drivers. (Hochstein, 2007) Further, intersections with offset left-turn lanes were determined to be safer than those with conventional left turn lanes. (Khattak, 2006; Davis, 2007) However, Davis also concluded that signalization had no effect on expected crash frequency. Mueller's study of left-turn phases also concluded that protected-only phasing on the major approach resulted in an increase in rear-end crashes, a decrease in angle crashes, and no change in left-turn crashes. (Mueller, 2007)

#### **2.4.3.3. Truck Traffic**

Zimmerman tested the implementation of a detection-control system to reduce the likelihood a truck would be caught in a traffic signal's dilemma zone. The system can determine the length of the truck and provide appropriate advanced warning. (Zimmerman, 2006) Extending the amber phase by 1.5 seconds was found to provide adequate safety improvement without affecting intersection efficiency. The report concluded safety benefits by providing advanced warning to large trucks. (Zimmerman, 2007)

#### **2.4.3.4. Crash Reduction Factors**

The FHWA's *Desktop Reference for Crash Reduction Factors* provides several countermeasures used by engineers to increase the safety of intersections. The guide lists countermeasures with associated percentage crash reduction factors (CRFs) by crash type, severity, area type, and traffic control. Measures of effectiveness, including the standard error and range, are reported for most countermeasures. (FHWA, 2007)

### **2.5. Artificial Intelligence Systems**

#### **2.5.1. Introduction**

The traditional approach to making engineering decisions involves a mix of relevant experience, education, and accepted standards. Complications arise when an analyst or decision-maker lacks access to one or more of these components. The lack of experience is difficult to resolve in many circumstances. Experienced engineers rely on a system of rules founded on a combination of factual knowledge and problem solving techniques developed over their career on similar projects. (Bryson, 1987) Artificial intelligence systems may be helpful when engineering experience is not available.

Transportation and traffic safety engineering has existed, in some form, since the early stages of the development of the transportation system. Through experience and practical engineering applications, safety has consistently been improved for all modes of transportation. Work in the transportation safety field has resulted in decades of experience, and created an overall body of knowledge useful in managing transportation safety. Due to the difficulties in

passing existing knowledge to future engineers, several agencies responsible for managing transportation safety have not been able to utilize this knowledge to its fullest extent.

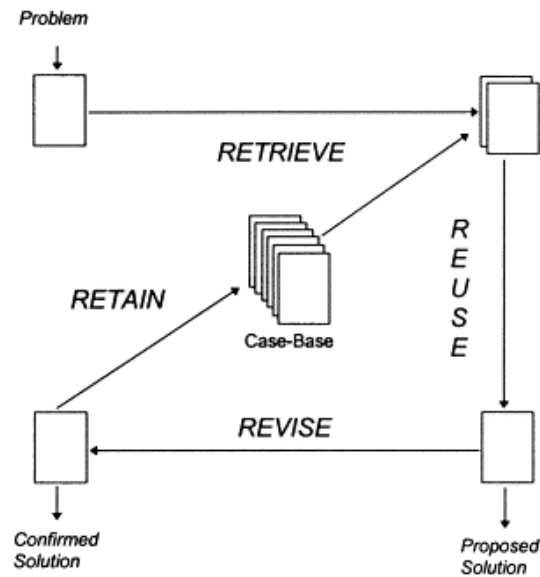
(Seneviratne, 1990) An approach to reducing these losses is the development of a knowledge-based system for transportation safety.

### **2.5.2. Artificial Intelligence**

Artificial intelligence (AI) systems were originally developed in the mid-1950s for use as a system to aid in complex problem solving applications. An AI system processes information using a combination of algorithms based on a hierarchy of rules established by the system creator or user. (Crevier, 1993) AI can be viewed as a broad term used to describe tools aiding in the decision-making process. A sub-category of AI systems is knowledge-based (KB) systems, which use previous experience or knowledge to provide a solution to a desired problem. (Spring, 2007) A KB system is defined as a system that uses stored knowledge to solve problems in a particular domain. (Spring, 2007) (Thinkquest, 2008) KB systems provide an established and repeatable approach for determining solutions to complex problems, and allow adjustments to the system as additional relevant data become available. (Spring, 2007) Established and repeatable approaches to solutions that could be enhanced by engineering experience have direct applicability to the decision-making process for the signalization of expressway intersections, especially in the lack of complete information or with limited numbers of comparable sites.

A type of KB approach is case-based reasoning (CBR). CBR is a decision-making process that proposes solutions to a problem by using previous solutions to similar problems. (Watson, 1999) CBR “retrieves the most similar case and adapts to the new situation”. (Spring, 2007) Figure 1 shows the four Rs of CBR: retrieve, reuse, revise, and retain. The CBR cycle

retrieves similar cases, reuses prior results, revises the results for the target situation, and retains the results for further use. CBR systems, as applied to engineering projects, may be thought of as a non-traditional way of utilizing engineering experience. (Watson, 1999)



(Source: Watson, 1999)

**Figure 1. Case-Based Reasoning Four R Cycle**

CBR consists of several operation techniques. Two such techniques are 1) nearest neighbor and 2) fuzzy logic. Nearest neighbor CBR considers similarity of comparison cases to a candidate case to determine a “percentage of similarity”. Next, this similarity is used to determine the applicability of the prior (comparison) solutions to the candidate problem. Fuzzy logic establishes qualitative terms to describe the similarity of problems for assisting in choosing solutions. (Watson, 1999) Qualitative terms used such as excellent, good, fair, and poor may be used to describe the importance of similarity of certain features, such as those that may characterize high-speed expressway intersections. CBR systems can provide an effective means to utilize previous experience, as well as a method for assigning measures of similarity that facilitates accessing this experience.

### 2.5.3. Artificial Intelligence Systems in Use

KB systems have been used for transportation related issues including planning construction activities, diagnosing hazardous highway locations, designing structures, and planning freight applications. KB systems include expert systems that have been used in engineering applications. (Spring, 2007) A relevant and recent application of expert systems is the Intersection Diagnostic Review Module of the *Interactive Highway Safety Design Model (IHSDM)* developed by the FHWA for use on rural two-lane highways. The IHSDM intersection diagnostic review module uses an expert system which applies rules of good engineering practice and provides a comprehensive review of intersection design. The system also recommends changes or improvements when warranted. The IHSDM expert system highlights potential safety flaws, based on a severity scale, for engineering review. The IHSDM review module was developed with the intent of providing a systematic procedure to replace or augment the conventional design and review practices used by engineers. (Kindler, 2003)

Many KB systems are currently in use and more are under development. (Spring, 2007) While the extent of KB systems use in transportation safety engineering is limited, a few systems have been developed. For example, a decision-support system for managing highway safety was developed in Greece for applications of various safety improvements. (Chassiakos, 2005) The system is based on road and accident data, results from past research, and expert opinions. Decision-support, based on information entered into the system, provides the user with a list of candidate measures for safety improvement. A limitation of the system is the amount of data required to characterize the study area and site. Researches advise that an evaluation period is needed to ensure that the suggested improvements actually enhance the safety performance.

A KB system has also been developed for managing intersection safety based on a series of multiple choice questions. (Seneviratne, 1990) This KB system can be used to assist engineers in selecting the most appropriate and efficient countermeasures. Questions were created by three practicing engineers and two university researchers with knowledge of intersection safety. The system suggests countermeasures and probability of effectiveness based on the answers to the questions. Limitations include a subjective degree of belief in certain improvements or remedies, and disagreements on their perceived effectiveness. This KB system was never put into practice.

A traffic safety expert system, Knowledge-Based Local Traffic Safety Support (KLOTS) system, was developed and implemented in Sweden. The KLOTS system was a part of Sweden's "vision zero" program that established a goal of zero fatalities on their transportation system. KLOTS provides the user with a list of countermeasures divided into three categories based on the likelihood of the countermeasure's effectiveness. The system has been and is currently being used by the Swedish National Road Administration, consultant engineering companies, and universities. Since the test application of KLOTS in 1990, three additional updates have been completed. User reviews of the KLOTS system and the generated countermeasures have been considered favorable and very successful. (Herland, 2000)

A prototype KB system for supporting the investigation of high-crash two-way stop controlled intersections and appropriate countermeasures, was developed at Purdue University for the Indiana Department of Transportation. (Kwasniak, 2007) The KB system followed a decision-tree path of road, weather, and traffic conditions to determine the appropriate safety countermeasure to be applied. The experience or expert knowledge was derived through the use of checklists similar to safety reviews and personal interviews. The system was tested by



comparing the results of inexperienced engineers using the system to those of experienced engineers without the system. The two groups were found to often choose the same or similar countermeasure. During the experiment, it was determined that some of the experts chose the incorrect countermeasure due to human error. The KB system, in fact, reduced the likelihood of human errors affecting the choice of countermeasures.

#### **2.5.4. KB System Validation**

Once a KB system has been created and tested, an appropriate next step is to validate the system. Validating a system involves verifying the accuracy and completeness of the system. The validation may consist of comparing the results of the system to the opinions of experts. (Demetsky, 1992) In some cases, additional data are needed to validate the results. (Herland, 2000) Validation enhances confidence in the system. If user confidence is weak, a system should be reevaluated. (Demetsky, 1992)

#### **2.5.5. Conclusion**

No explicit guidance can be found that can be used to determine the safety effectiveness of signalizing a high speed expressway intersection. Prior studies suffer from limited data or improper use of statistics. Safety effectiveness at a particular location would seem to depend on many site characteristics which make each case nearly unique. Sometimes signals improve safety, and other times they do not. Case-based reasoning seems, therefore, to have the potential for organizing previous experience in a way that can assist the engineer in making sound judgments and if warranted, properly designing the signalized high expressway intersection.

## **Chapter 3 Case-Based Reasoning Tool Development**

### **3.1. Introduction**

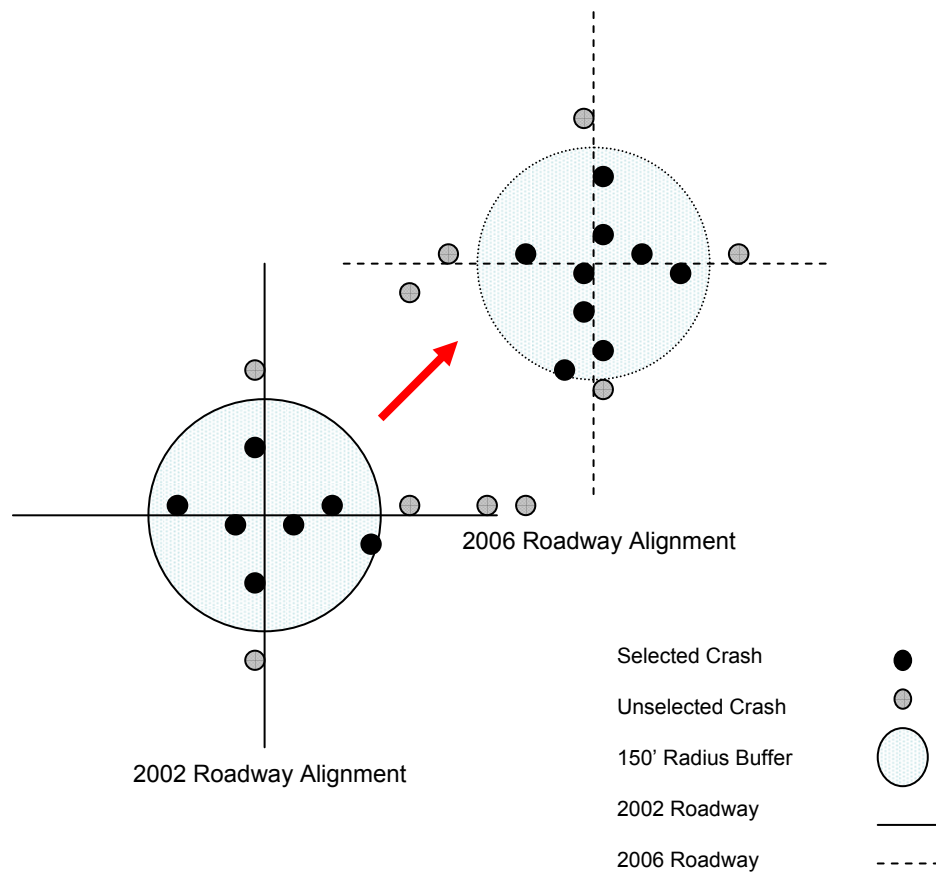
To assist engineers considering signaling high-speed expressway intersections, a case-based reasoning tool was developed. This spreadsheet based tool contains data for comparison intersections and uses these data to demonstrate potential signalized crash performance for candidate intersections. Two approaches, herein called “similarity” and “attribute match”, are implemented in the tool. The development of the tool is discussed within this chapter.

### **3.2. Intersection Selection**

Comparison intersections were identified using three methods: examination of previous studies, personal knowledge of locations, and a query of the IaDOT’s roadway database. Several high-speed signalized intersections were previously located by Knox. (Knox, 2005) A focus group of regional transportation engineers identified additional locations. Still others were identified using the IaDOT Geographic Information Management System (GIMS) database which contains information on the traffic control type, roadway type, and speed of each section of roadway in Iowa. Queries developed for this purpose may be found in Appendix A. Each intersection location was assigned an intersection node number. Locations were verified by site visit, inspection of IaDOT video logs, or observation of aerial images.

The GIMS roadway database is updated each year with new geometric and traffic information. Improving cartography often results in a shift of the database representation of geometric alignment. As crashes are located on various versions of the cartography, most

intersection locations “shifted” at least once in the 2002 to 2006 analysis period. These “shifts” are illustrated in Figure 2. These shifts must be checked and accounted for in the selection of intersection locations and crashes. Multiple circular GIS buffers based on intersection points from each year’s base cartography were created to select crashes.



**Figure 2. Roadway Geometric Alignment Shift**

### 3.3. Crash Selection

Crashes for the 2002 through 2006 analysis period were selected based on the spatial proximity to each intersection. Typically, safety analysis staff of the IaDOT use a standard radius from intersection center to select crashes where a buffer of 75 feet is used in urban areas and 150 feet is used in rural areas. Rural analysis uses a higher radius due to typically higher speeds and lower road network density in these areas.

As all intersections in this research may be classified as high-speed, 150 feet was used as the buffer distance for this work. The frequencies of selected crashes (sorted by main road speed limit) are shown in Table 1.

45 Miles Per Hour		
Total Crashes	Number of Intersections	Crashes/Intersection
2,515	71	35.42
50 Miles Per Hour		
Total Crashes	Number of Intersections	Crashes/Intersection
565	20	28.25
55 Miles Per Hour		
Total Crashes	Number of Intersections	Crashes/Intersection
1,261	43	29.33
All Speeds		
Total Crashes	Number of Intersections	Crashes/Intersection
4,341	134	32.40

**Table 1. Number of Crashes for each Speed Limit and All Speed Limits**

To verify the accuracy of crash assignment to intersections, the “intersection related” crash attribute was examined. Approximately 75 percent of all selected crashes indicated “intersection related”. Seventy-five percent is considered acceptable due to the subjective nature of the “intersected related” attribute.

### 3.4. Intersection Data Collection

The geometric and traffic attributes of study intersections were assembled using various data collection methods. As GIMS covers all roads in the state, the database provided many intersection attributes. However, key attributes were not included. As a supplement to GIMS, aerial images were used to verify the locations and geometric layout of intersections. As many of the intersections are located on state maintained roads, supplementary information was also obtained using IaDOT video logs. Finally, off-system intersections required site visits.

The assembled intersection attributes are listed in Table 2. These characteristics are used to compare intersections in the case-based reasoning tool (below), and are based on the most current data available (whereas crash data are for the period 2002-2006).

Major Roadway: Traffic Volume	Major Roadway: Presence of Right-Turn Lane
Minor Roadway: Traffic Volume	Major Roadway: Presence of Left-Turn Lane
Major Roadway: Horizontal Curvature	Major Roadway: Median Type
Major Roadway: Longitudinal Grade	Major Roadway: Median Width
Major Roadway: Speed Limit	Major Roadway: Left-Turn Phasing
Major Roadway: Number of Through Lanes	Major Roadway: Advanced Warning Sign
Number of Intersecting Roadways	Rural/Urban Intersection Location
Intersection Lighting	

**Table 2. Intersection Attributes and Characteristics**

### 3.5. Spreadsheet Case-Based Reasoning System

A case-based reasoning tool to facilitate making safety-based decisions on signalization was developed using two approaches: expert opinions on “similarity” and exact attribute match. In both systems, a candidate intersection for signalization may be compared to comparison signalized intersections in the database. The “similarity system” identifies similar intersections based on ranges of 16 attributes. The “attribute-matching” system identifies only comparison intersections where a subset of attributes fall in ranges that match identically with those in the comparison set (e.g., perhaps only those that have the same speed or volume class). In each system, crash parameters for similar intersections are summarized and presented graphically to the user. The two systems are explained in more detail in the following sections.

#### 3.5.1. The Similarity System

The “similarity system” produces a “similarity” score between a candidate intersection and all comparison intersections. It can be used to determine a set of comparison intersections at various similarity levels. Default comparisons based on predefined similarity levels are provided, and the user is allowed to specify their own desired similarity level. The final product of the similarity system is crash experience tables and histograms based on actual intersection crash data as well as data adjusted by relevant crash reduction factors to match the expected performance of a candidate intersection based on its attributes.

Each level of similarity (e.g., 65%, 70%...) provides a different comparison set of intersections whose crash experience is summarized for the user to assist in the decision process. Specification of a higher degree of similarity will in general decrease the number of comparison intersections dramatically. An example table of the actual crash experience for a set of comparison intersections is shown in figure 3. The similarity system produces a table for

comparison intersections' actual performance and crash reduction factor (CRF) adjusted crash experience. The histograms for a trial run of the system showing the total crash rate at the similarity levels of .50, .60, and .70 are shown in Figures 4, 5, and 6.

	Total Number of Intersections	Crashes/Intersection	Fatal Crashes/Intersection
Selected	7.00	3.71	3.80
0.5 Similarity	127.00	3.71	3.80
0.6 Similarity	76.00	3.77	3.89
0.7 Similarity	76.00	3.91	4.09
0.8 Similarity	22.00	3.91	4.09
0.9 Similarity	22.00	0.00	0.00
1.0 Similarity	22.00	0.00	0.00
	Injury Crashes/Intersection	Total Crash Rate (C/MEV)/Intersection	Fatal + Injury Crashes/Intersection
Selected	3.91	1.42	4.09
0.5 Similarity	3.87	1.41	3.98
0.6 Similarity	3.71	1.43	3.80
0.7 Similarity	3.71	1.43	3.80
0.8 Similarity	3.77	1.38	3.89
0.9 Similarity	3.91	1.42	4.09
1.0 Similarity	3.91	1.42	4.09
	Fatal + Injury Crash Rate	Fatal Crash Rate (FC/HMEV)/Intersection	Injury Crash Rate (IC/MEV)/Intersection
Selected	0.21	1.02	0.20
0.5 Similarity	0.17	0.48	0.17
0.6 Similarity	0.18	0.45	0.18
0.7 Similarity	0.18	0.45	0.18
0.8 Similarity	0.20	0.64	0.20
0.9 Similarity	0.21	1.02	0.20
1.0 Similarity	0.21	1.02	0.20

**Figure 3. Example of Crash Experience Table for the Similarity System**

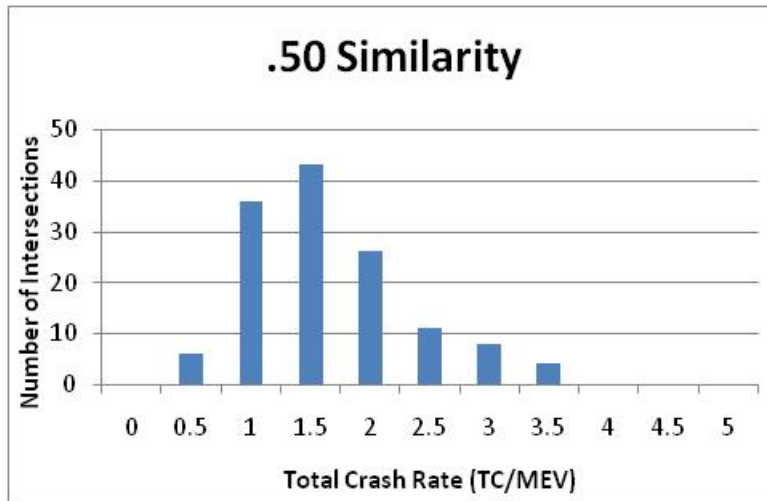


Figure 4. Example of Histograms for Total Crash Rate with 0.50 Similarity

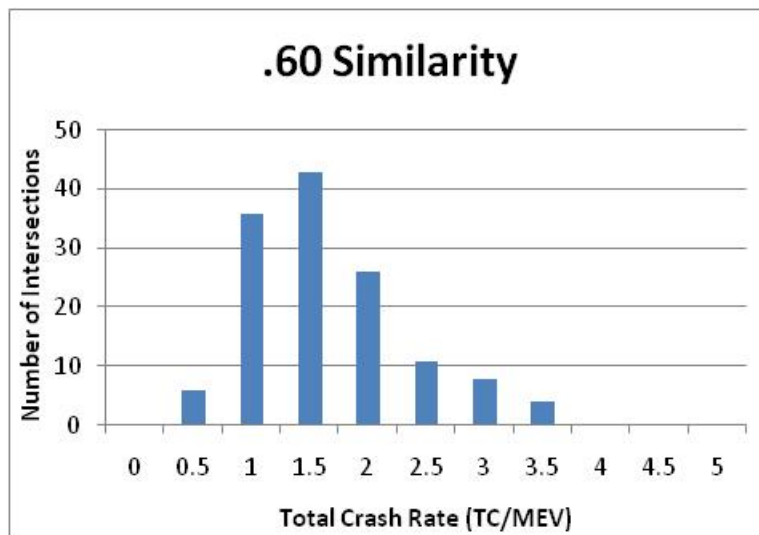
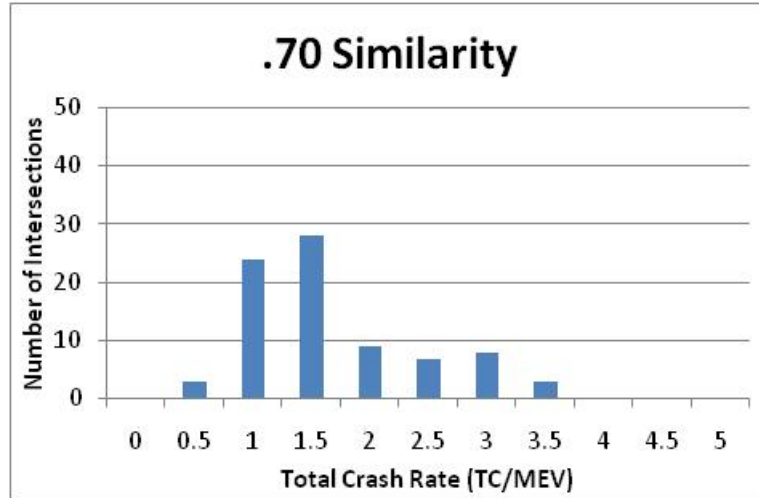


Figure 5. Example of Histograms for Total Crash Rate with 0.60 Similarity





**Figure 6. Example of Histograms for Total Crash Rate with 0.70 Similarity**

The similarity score is comprised of a weighted average of similarity ratings developed for each intersection attribute. The weights were determined by an expert panel of transportation engineers. The panel was surveyed on the importance of a given intersection characteristic in determining the similarity of intersections according to anticipated safety performance. They were asked to rate each attribute from low (one) to high (ten) importance. The survey form given to each expert is in Appendix B. Figure 7 lists the inputs obtained from the expert panel. Attribute weights were calculated using the following formula:

$$Weight = \frac{\sum Value\ of\ expert's\ opinion\ for\ attribute}{\sum Value\ of\ expert's\ opinion\ for\ all\ attributes}$$

**Equation 1. Attribute Weight**

Expert Ranking Values	Major Traffic Volume	Minor Traffic Volume	# of Intersecting Roads	Rural/Urban	Number of Lanes	
Expert #1	8	8	10	10	9	
Expert #2	10	10	5	10	8	
Expert #3	10	10	10	10	10	
Expert #4	10	10	6	8	7	
Expert #5	10	10	8	5	2	
Expert #6	10	10	7	9	8	
Expert #7	10	10	7	1	8	
Expert #8	9	9	10	8	8	
Expert #1	8	8	10	10	10	
Expert #2	10	10	6	10	8	
Expert #3	10	10	10	10	10	
Expert #4	10	10	6	8	8	
Expert #5	10	10	8	6	2	
Expert #6	10	10	8	10	8	
Expert #7	10	10	8	2	8	
Expert #8	10	10	10	8	8	
SUM	78	78	66	64	62	348
Attribute Weight	0.22	0.22	0.19	0.18	0.18	1.00

**Figure 7. Expert Panel inputs to the Similarity System**

The similarity system displays actual crash experience from comparison intersections and CRF adjusted crash experience at various similarity levels. The comparison intersection actual crash experience is based on the real crash data from the intersection. The comparison intersection CRF adjusted crash experience is determined by adjusting the candidate intersection's crash experience.

The determination of the CRF adjusted crash experience is accomplished by a two step process. The first step is to adjust the comparison intersection performance based on CRFs for safety features present at each comparison intersection to produce a "normalized" crash performance. This is accomplished via application of equation 2. The second step, as shown in equation 3, applies the CRFs for the attributes of the candidate intersection to produces expected crash performance if comparison intersections had features exactly similar to the candidate intersection.

*Normalized Comparison Intersection Crash Performance*

$$= \frac{\text{Actual Comparison Intersection Crash Performance}}{(1 - CRF_A) * (1 - CRF_B) * (1 - CRF_i)}$$

**Equation 2. Normalized Comparison Intersection Crash Performance**

*Adjusted Comparison Intersection Crash Performance*

$$= ((1 - CRF_A) * (1 - CRF_i)) * \text{Removed CRF Crash Data}$$

**Equation 3 Adjusted Comparison Intersection Crash Performance**

The attribute CRFs are derived from the *Desktop Reference for Crash Reduction Factors* published by FHWA. (FHWA, 2007) The reference guide lists several countermeasures that may be applied to roadways, intersections, and pedestrian facilities. Each countermeasure is assigned a crash reduction factor as the percentage crash reduction that might be expected after implementation.

Similarity is calculated based on the matching of five attributes between the candidate intersection and the comparison intersection. The five attributes used for the similarity score are shown in the top row of figure 7. The expert opinion weights are added to the comparison intersection's similarity score if the intersections have a matching attribute. The equation for similarity is shown in equation 4.

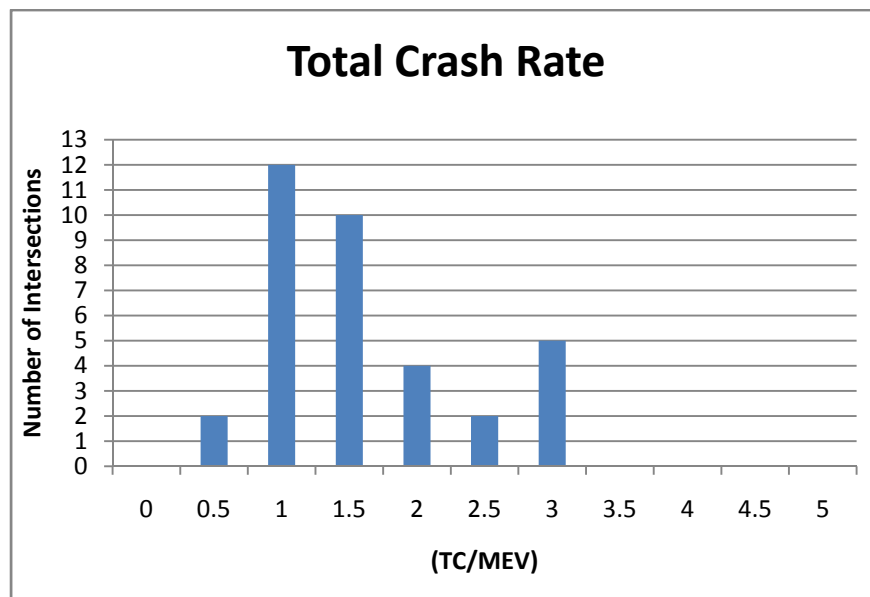
$$\text{Similarity} = \frac{\sum \text{MATCHING attribute weights}}{\sum \text{MAX attribute weights}}$$

**Equation 4. Comparison Intersection Similarity**

Once the score is calculated, summary crash experiences and histograms are provided for all intersections that satisfy the selection criteria.

### 3.5.2. The Attribute Match System

The “attribute match” system, the user decides on a subset of attributes to be used for comparison, allowing the user to have more control over the features that, in their opinion, provide the best comparison set. The system then uses these attributes to identify comparison intersections that “exactly” match the candidate intersection and provides summary graphical and tabular safety performance data for the matching comparison intersections. Specification of a large number of attributes will in general decrease the number of comparison intersection dramatically. Figures 8 through 10 show the graphs resulting from a trial run of the “attribute match” system.



**Figure 8. An Example of the Attribute Match System for Total Crash Rate**

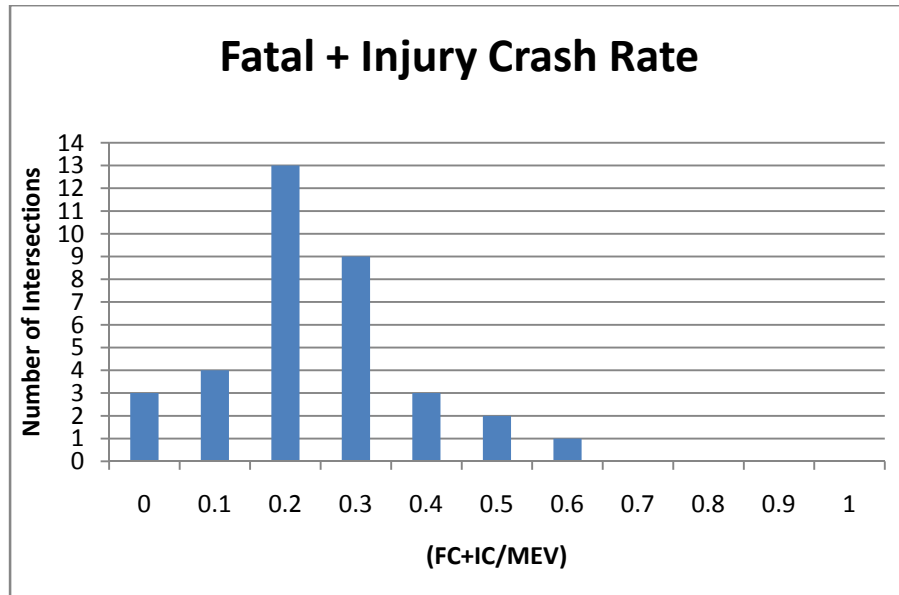


Figure 9. An Example of the Attribute Match System for Fatal Plus Injury Crash Rate

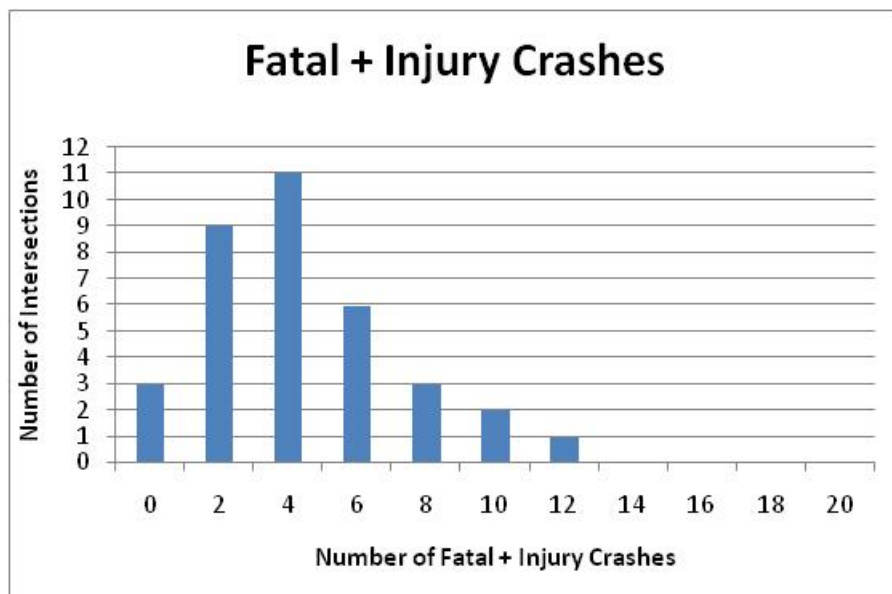


Figure 10. An Example of the Attribute Match System for Fatal Plus Injury Crashes

## **Chapter 4 Application**

### **4.1. Introduction**

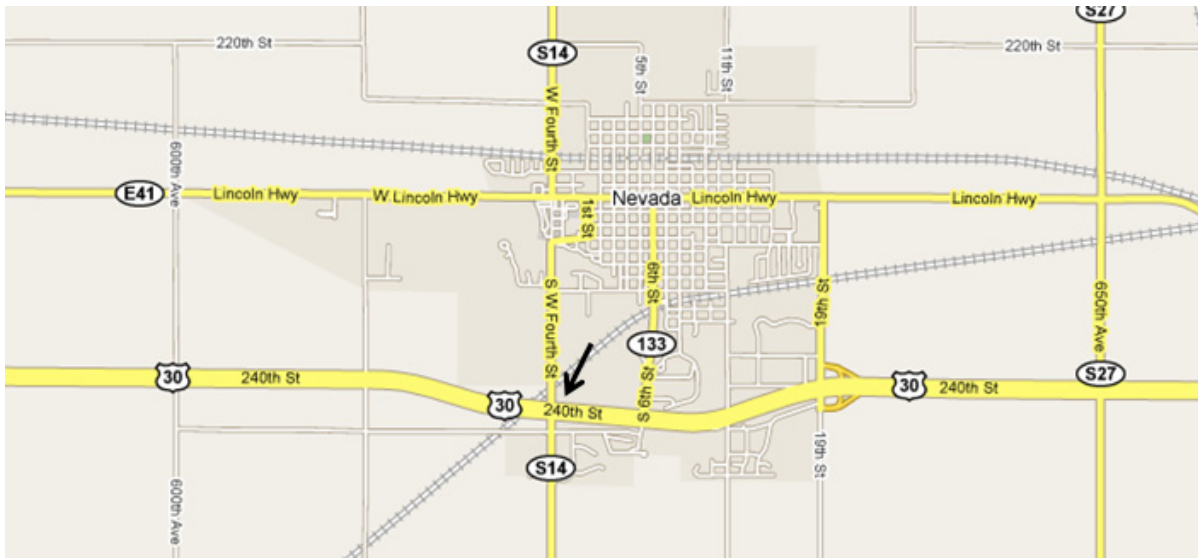
In addition to investigating the potential safety effectiveness of signalization, the intersection signalization case-based reasoning tool can be used to investigate the effectiveness of other intersection modifications as well as assessing the relative performance of existing signalized operations. This chapter presents four example applications of the tool highlighting the use of the 1) similarity system for safety performance prediction, 2) attribute matching system for safety performance prediction and testing the possible effects of features such as left-turn protection, 3) similarity system for safety audit of an existing signalized location, and 4) similarity system for alternatives analysis (evaluating the potential safety effects of changes in traffic, control, or geometry).

The functionality of the case-based tool is demonstrated using crash and attribute data from two Iowa high-speed expressway intersections. For the first two applications, a two-way stop controlled site is studied. For the last two, an existing signalized site is the focus. In all cases, the CBR tool provides summary safety performance data for comparison intersections including histograms for total crash rate, fatal crash rate, and fatal plus injury crash rate for various similarity levels. The tool also provides safety performance values for each comparison intersection to support in depth evaluation.

### **4.2. Application 1: Similarity System for Safety Performance Prediction**

In this application, the case-based tool is used to determine the effect signalization will have on intersection safety. For this application, a two-way stop-controlled expressway intersection is studied, with attributes and crash performance as shown in Table 3. The location of this intersection is U.S. 30 at County Road S14 in Nevada, Iowa (see Figure 11). The crash

rate for this intersection is 1.465 crashes per million entering vehicles (MEV) and 0.20 fatal and injury (K+A+B or fatal, major, and minor injury) crashes per MEV. A prominent feature of this intersection is the presence of a crest vertical curve due to a railroad overpass which limits sight distance. There is a speed limit change from 65 MPH to 55 MPH immediately to the west of the intersection.



**Figure 11. Location of Stop-Controlled Intersection for Applications 1 and 2**

The proposed attributes for the candidate signalized intersection are shown in Table 4. These changes include the addition of a signal with permitted/protected phasing, full lighting, advanced warning signs, and reduced horizontal curvature. Table 5 displays the actual average crash experience for comparison intersections which is similar to the proposed intersection configuration and table 6 displays the candidate intersection CRF adjusted crash experience for the comparison intersections. Similarity levels range from 0.50 to 1.00. A “selected” similarity of 0.75 is also presented (this number can be chosen by the user). Figures 12 through 18 present histograms for candidate intersection CRF adjusted total crash rates of the comparison intersections. The next set of figures, Figures 19 through 25 present similar charts for fatal plus

injury crash rate while figures 26 through 32 present the same types of graphs for fatal plus injury crash frequencies. All of the figures are based on the adjusted crash data for the 2002 to 2006 time period. On each graph and for comparison purposes, the relevant current crash statistic is presented for the existing unsignalized intersection.

<b>Present Attributes and Features</b>	
<b>Major Roadway: Entering Vehicles</b>	6,850
<b>Minor Roadway: Entering Vehicles</b>	1,380
<b>Major Roadway: Horizontal Curvature</b>	Slight
<b>Major Roadway: Longitudinal Grade</b>	5-10%
<b>Major Roadway: Speed Limit</b>	55 MPH
<b>Number of Intersecting Roads</b>	4
<b>Major Roadway: Number of Through Lanes</b>	2
<b>Major Roadway: Left-Turn Phasing</b>	---
<b>Intersection Skew</b>	None
<b>Major Roadway: Left-Turn Lane</b>	Yes
<b>Major Roadway: Right-Turn Lane</b>	Yes
<b>Intersection Lighting</b>	Partial
<b>Major Roadway: Median Type</b>	Depressed
<b>Major Roadway: Median Width</b>	38 feet
<b>Major Roadway: Advanced Warning</b>	No

<b>2002 through 2006 Crash Experience</b>	
<b>Total Crashes</b>	22
<b>Fatal Crashes</b>	0
<b>Injury Crashes</b>	3
<b>Fatal + Injury Crashes</b>	3
<b>Total Crash Rate (C/MEV)</b>	1.465
<b>Fatal Crash Rate (FC/MEV)</b>	0.00
<b>Fat. + Inj. Crash Rate (F+IC/MEV)</b>	0.20

**Table 3. The Present Attributes, Features, and Crash Experience Application 1**



Attributes and Features for “Candidate” Intersection	
Major Roadway: Entering Vehicles	6,850
Minor Roadway: Entering Vehicles	1,380
Major Roadway: Horizontal Curvature	None
Major Roadway: Longitudinal Grade	5-10%
Major Roadway: Speed Limit	55 MPH
Number of Intersecting Roads	4
Major Roadway: Number of Through Lanes	2
Major Roadway: Left-Turn Phasing	Permitted/Protected
Major Roadway: Presence of Left-Turn Lane	Yes
Major Roadway: Presence of Right-Turn Lane	Yes
Intersection Lighting	Full
Major Roadway: Median Type	Depressed
Major Roadway: Median Width	38 feet
Major Roadway: Advanced Warning	Yes

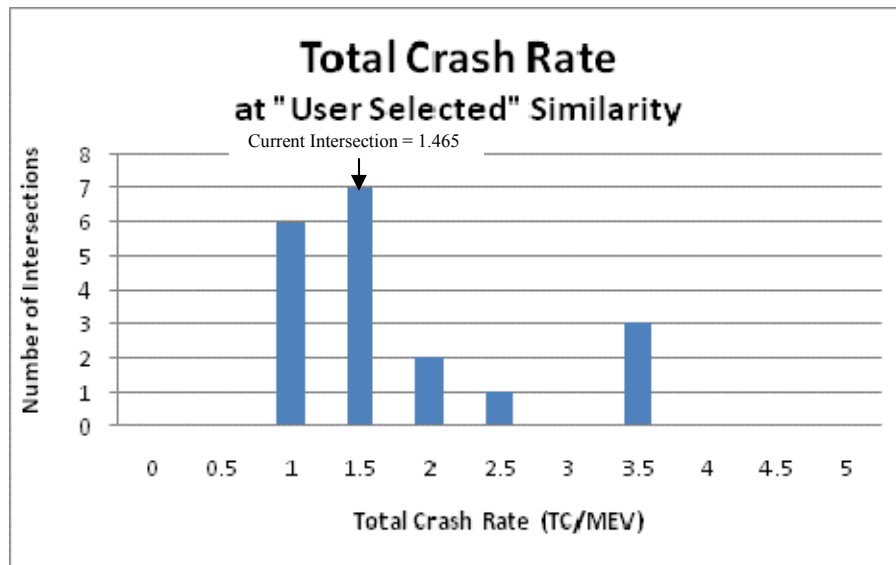
**Table 4. Proposed Attributes and Features for the Candidate Intersection**

	Total Number of Intersections	Crashes/Intersection	Fatal Crashes/Intersection
Selected	18.00	24.39	0.28
0.5 Similarity	70.00	26.94	0.19
0.6 Similarity	25.00	22.84	0.20
0.7 Similarity	18.00	24.39	0.28
0.8 Similarity	11.00	24.73	0.09
0.9 Similarity	1.00	20.00	1.00
1.0 Similarity	1.00	20.00	1.00
	Injury Crashes/Intersection	Total Crash Rate (C/MEV)/Intersection	Fatal + Injury Crashes/Intersection
Selected	3.11	1.58	3.39
0.5 Similarity	3.24	1.45	3.43
0.6 Similarity	2.84	1.49	3.04
0.7 Similarity	3.11	1.58	3.39
0.8 Similarity	2.55	1.59	2.64
0.9 Similarity	2.00	1.03	3.00
1.0 Similarity	2.00	1.03	3.00
	Fatal + Injury Crash Rate	Fatal Crash Rate (FC/HMEV)/Intersection	Injury Crash Rate (IC/MEV)/Intersection
Selected	0.21	1.88	0.19
0.5 Similarity	0.19	1.02	0.18
0.6 Similarity	0.19	1.35	0.18
0.7 Similarity	0.21	1.88	0.19
0.8 Similarity	0.16	0.47	0.16
0.9 Similarity	0.15	5.14	0.10
1.0 Similarity	0.15	5.14	0.10

**Table 5. Actual Crash Experience at the Levels of Similarity**

	Total Number of Intersections	Total Crash Rate	Fatal + Injury Crash Rate	Fatal + Injury Crash Frequency
<b>Selected</b>	18.00	0.93	0.16	2.80
<b>0.5 Similarity</b>	70.00	0.94	0.13	32.04
<b>0.6 Similarity</b>	25.00	0.79	0.12	2.18
<b>0.7 Similarity</b>	18.00	1.58	0.16	2.80
<b>0.8 Similarity</b>	11.00	0.57	0.07	2.80
<b>0.9 Similarity</b>	1.00	0.81	0.12	2.36
<b>1.0 Similarity</b>	1.00	0.81	0.12	2.36

**Table 6. CRF Adjusted Crash Experience**



**Figure 12. Adjusted Total Crash Rate for Application 1 "User Selected" Similarity of 0.75**

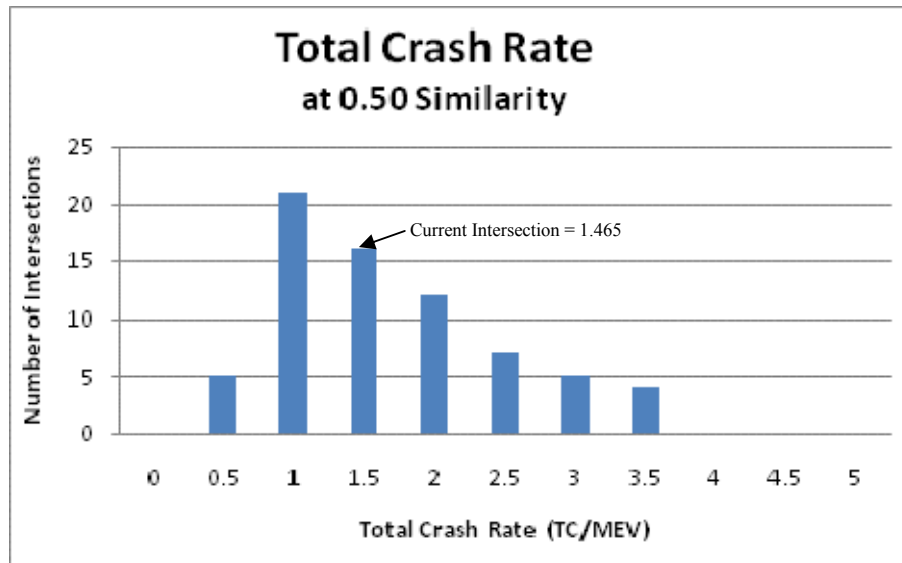


Figure 13. Adjusted Total Crash Rate for Application 1 with 0.50 Similarity

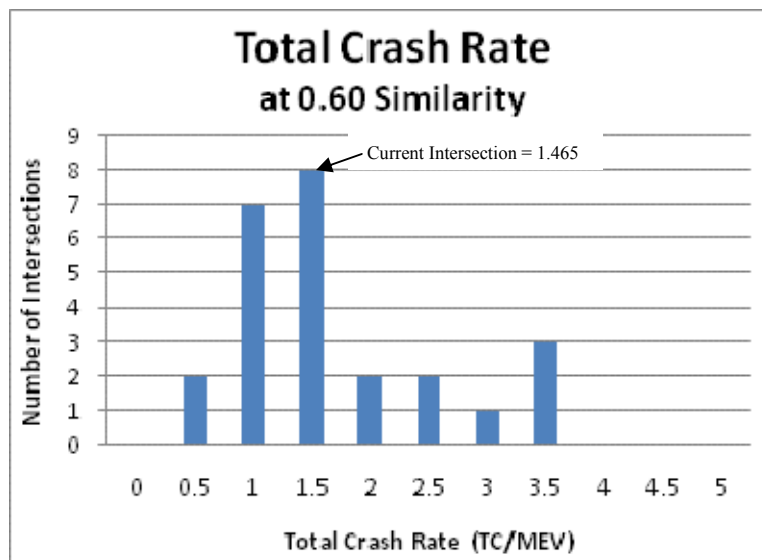


Figure 14. Adjusted Total Crash Rate for Application 1 with 0.60 Similarity

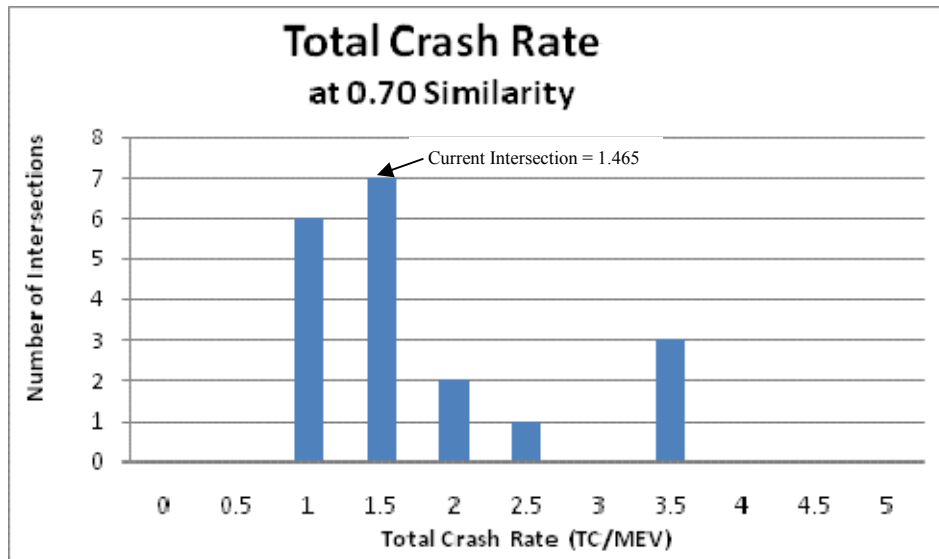


Figure 15. Adjusted Total Crash Rate for Application 1 with 0.70 Similarity

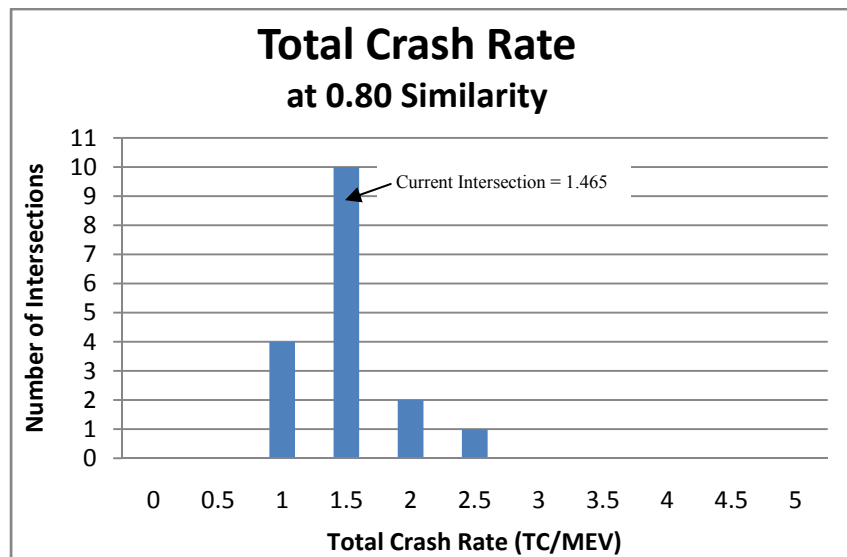


Figure 16. Adjusted Total Crash Rate for Application 1 with 0.80 Similarity

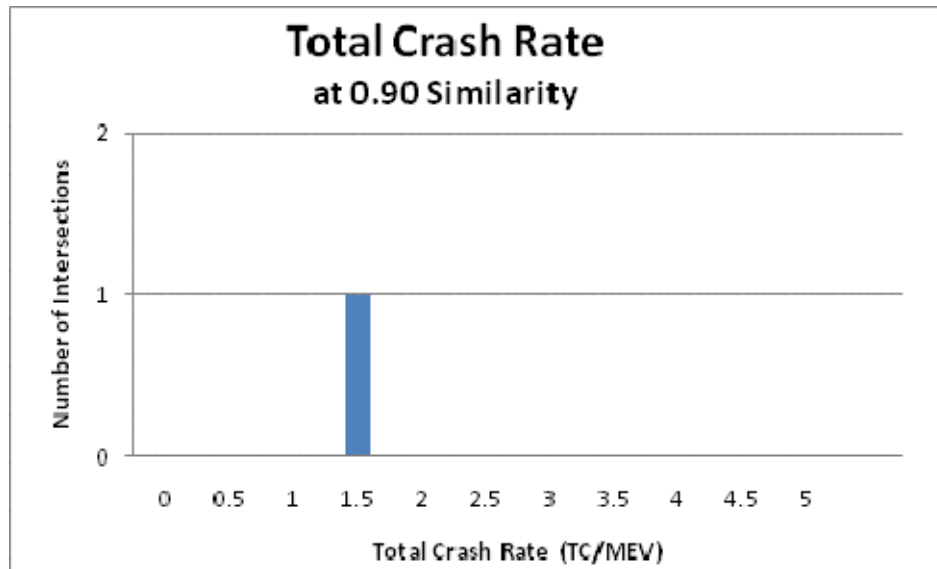


Figure 17. Adjusted Total Crash Rate for Application 1 with 0.90 Similarity

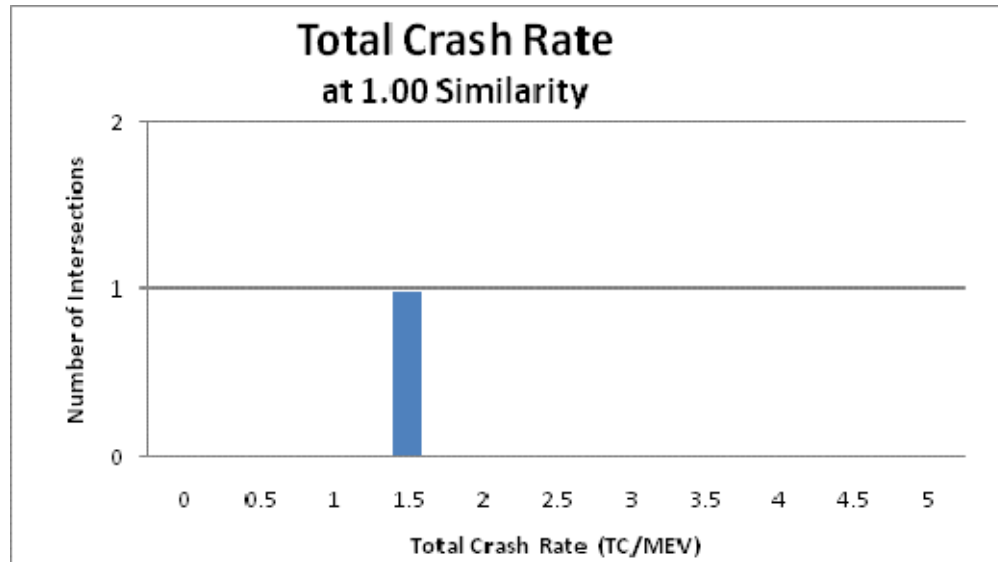


Figure 18. Adjusted Total Crash Rate for Application 1 with 1.0 Similarity

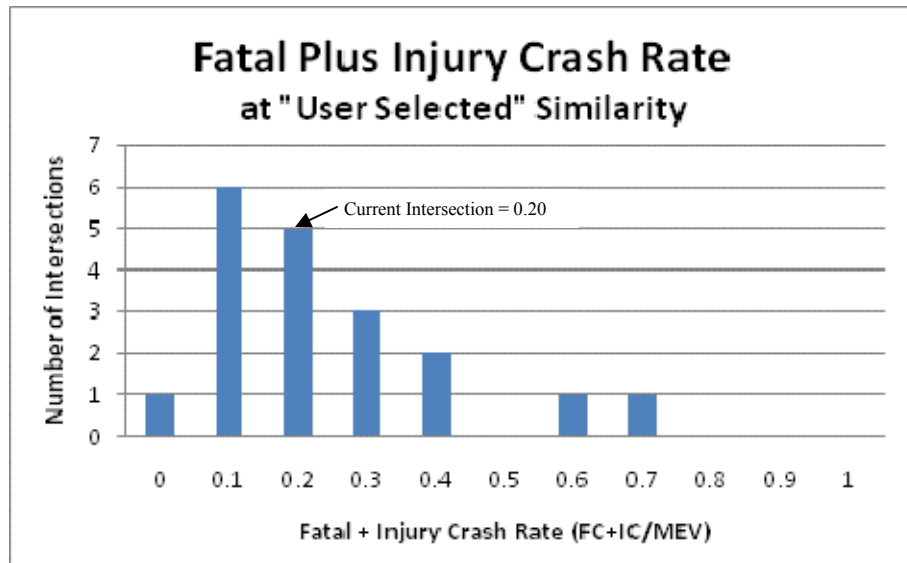


Figure 19. Adjusted Fatal + Injury Crash Rate for Application 1 “User Selected” Similarity of 0.75

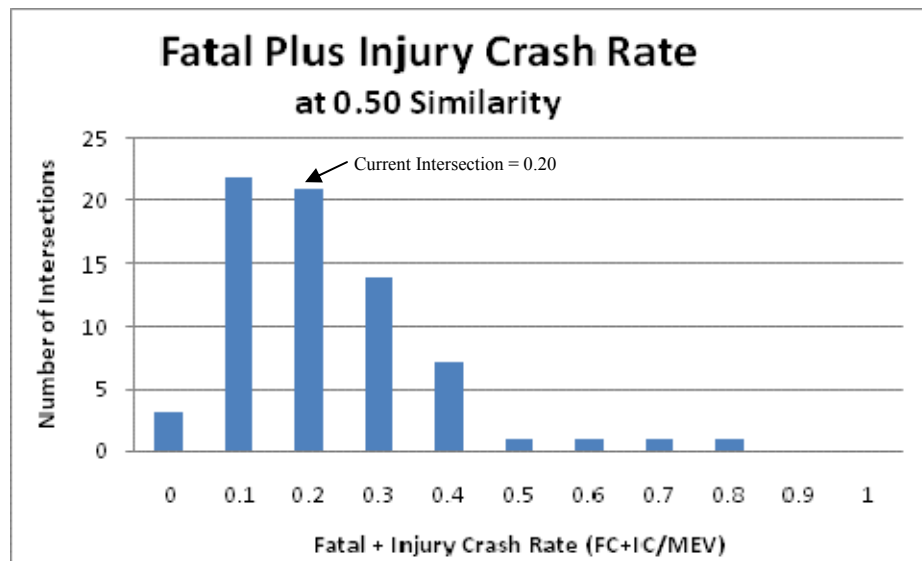


Figure 20. Adjusted Fatal + Injury Crash Rate for Application 1 with 0.50 Similarity

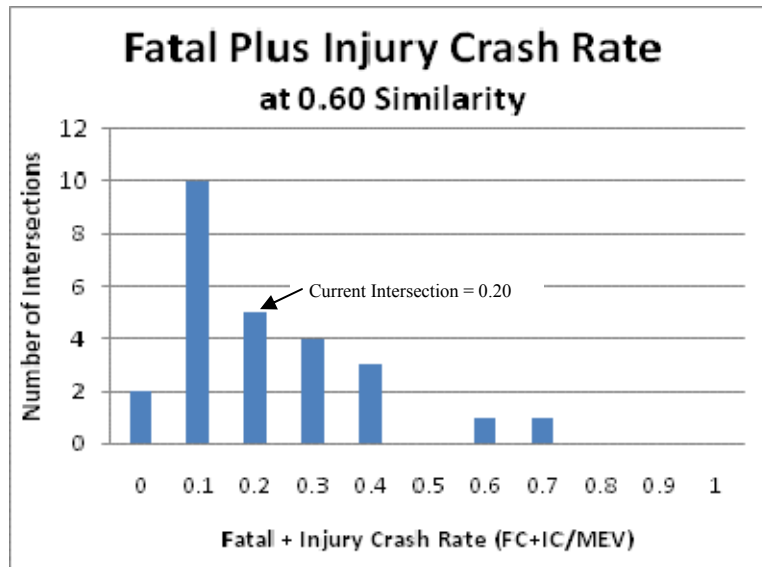


Figure 21. Adjusted Fatal + Injury Crash Rate for Application 1 with 0.60 Similarity

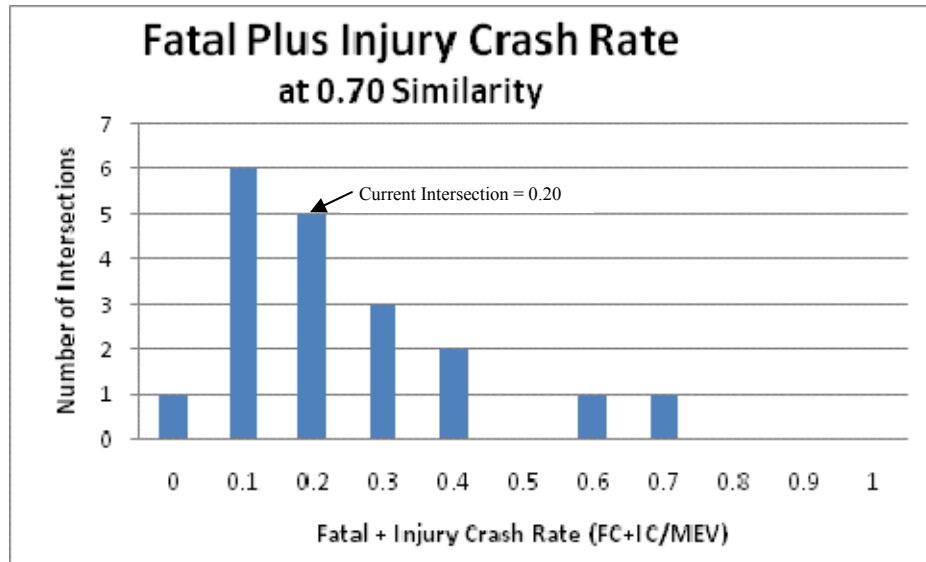
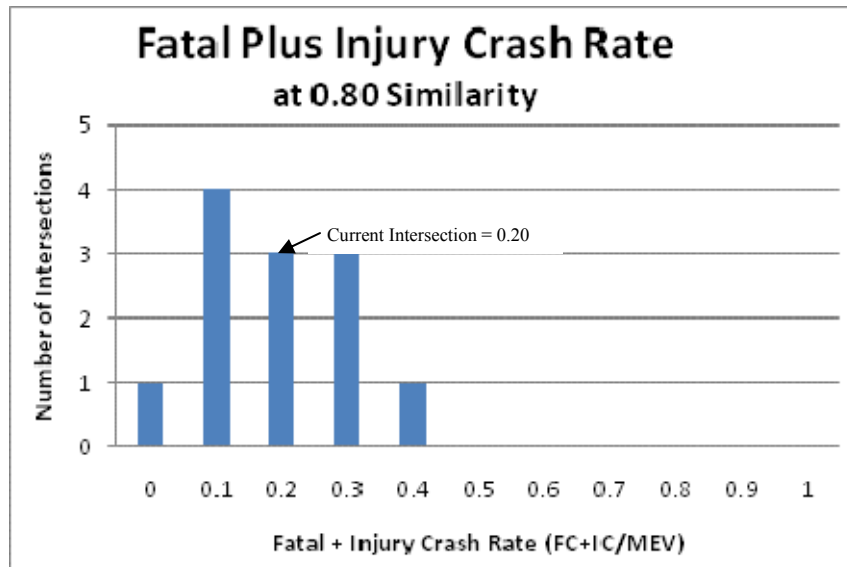
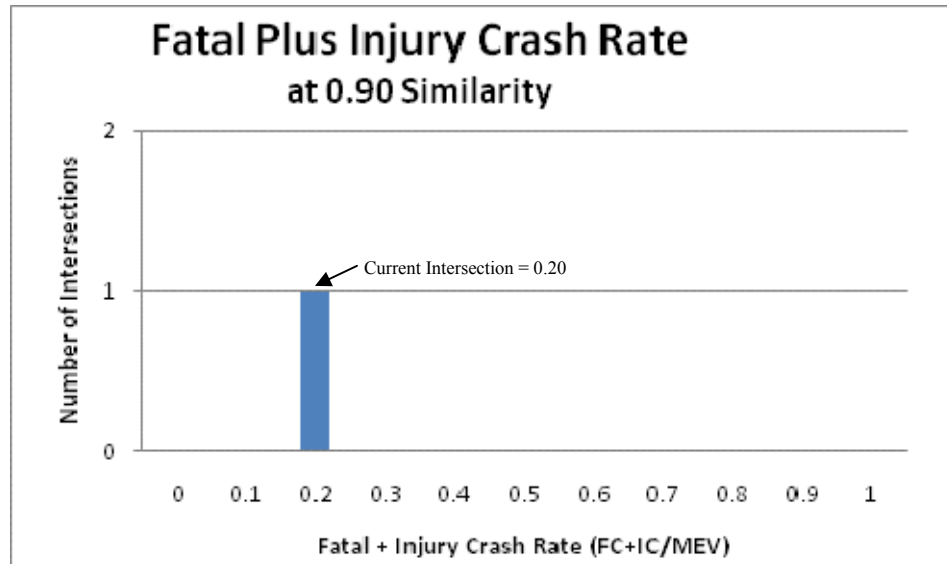


Figure 22. Adjusted Fatal + Injury Crash Rate for Application 1 with 0.70 Similarity



**Figure 23. Adjusted Fatal + Injury Crash Rate for Application 1 with 0.80 Similarity**



**Figure 24. Adjusted Fatal + Injury Crash Rate for Application 1 with 0.90 Similarity**



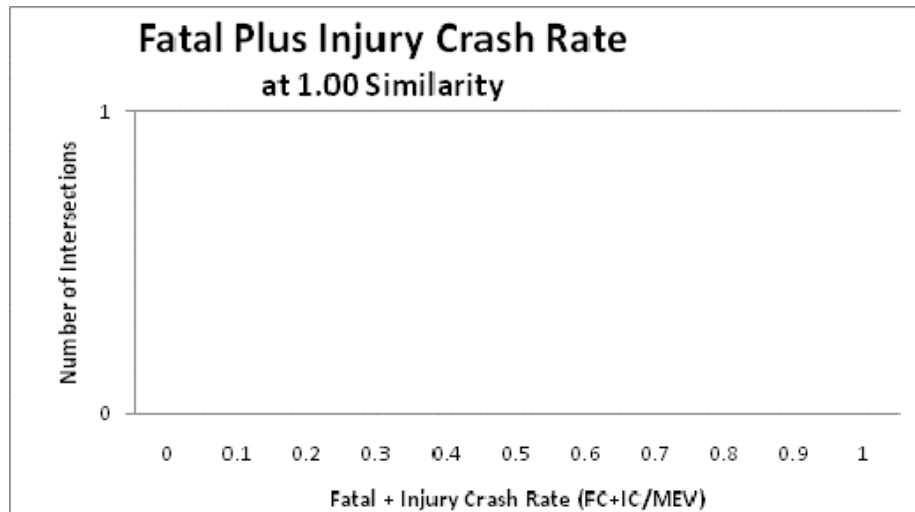


Figure 25. Adjusted Fatal + Injury Crash Rate for Application 1 with 1.0 Similarity

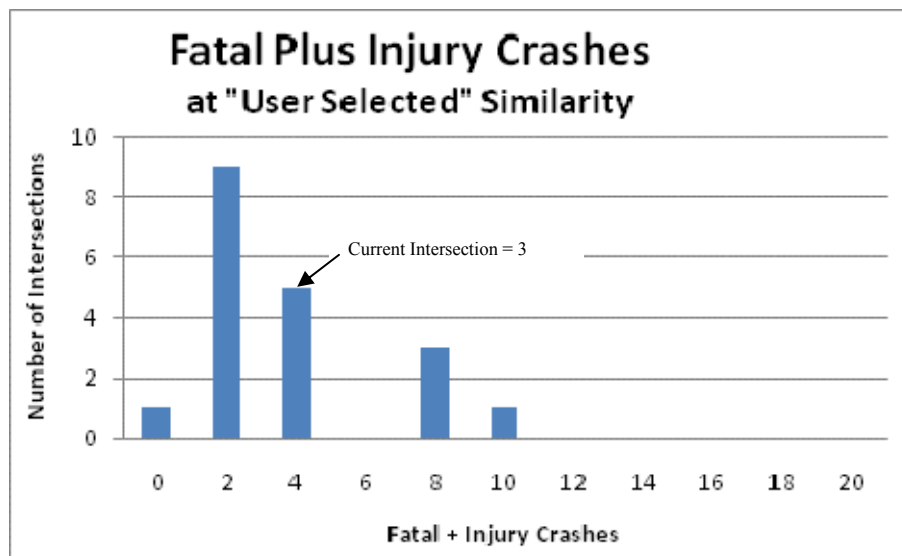
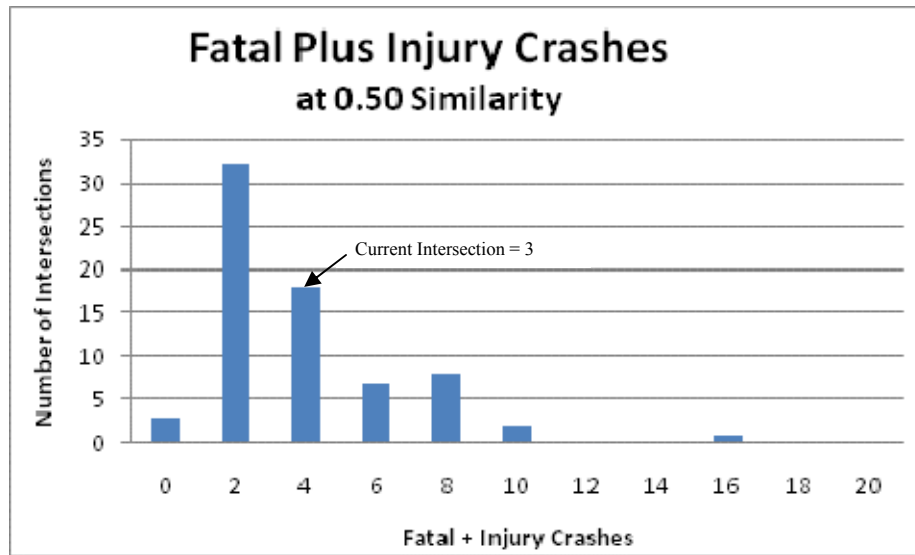
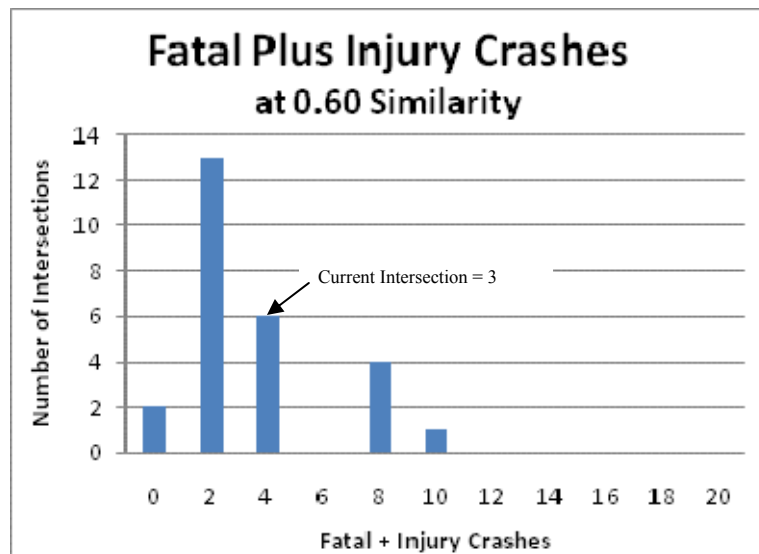


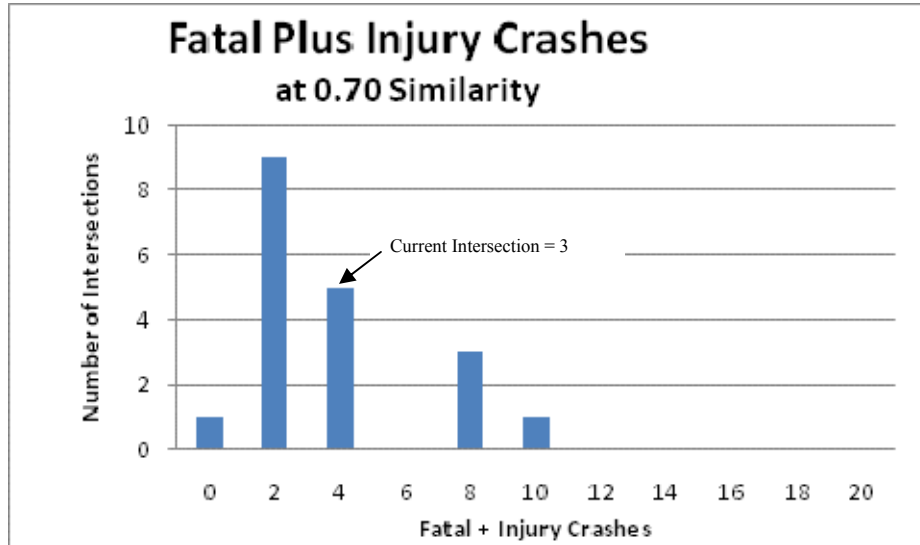
Figure 26. Adjusted Fatal + Injury Crashes for Application 1 User Selected Similarity of 0.75



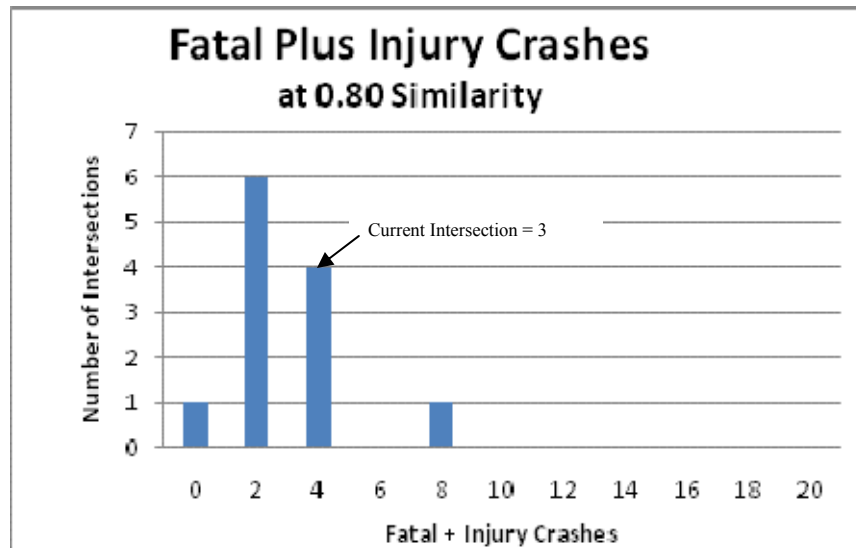
**Figure 27. Adjusted Fatal + Injury Crashes for Application 1 with 0.50 Similarity**



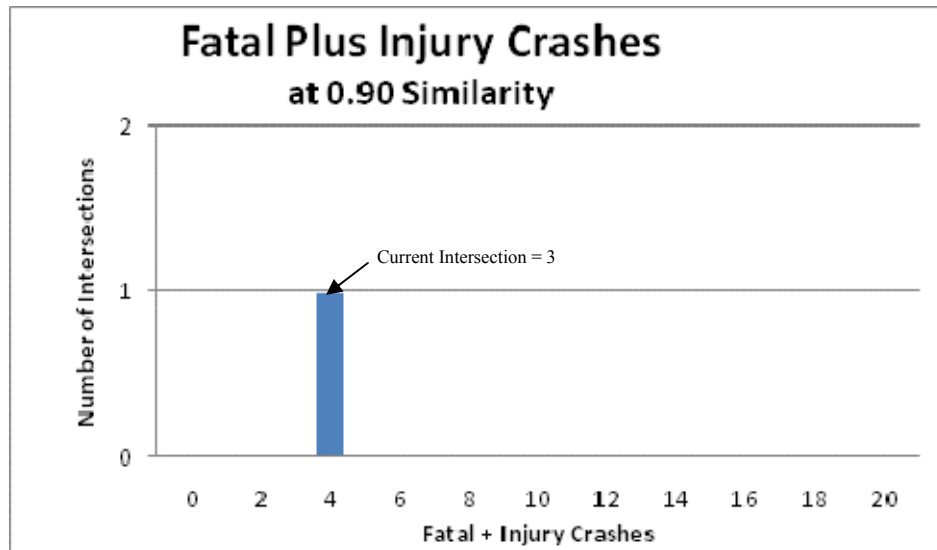
**Figure 28. Adjusted Fatal + Injury Crashes for Application 1 with 0.60 Similarity**



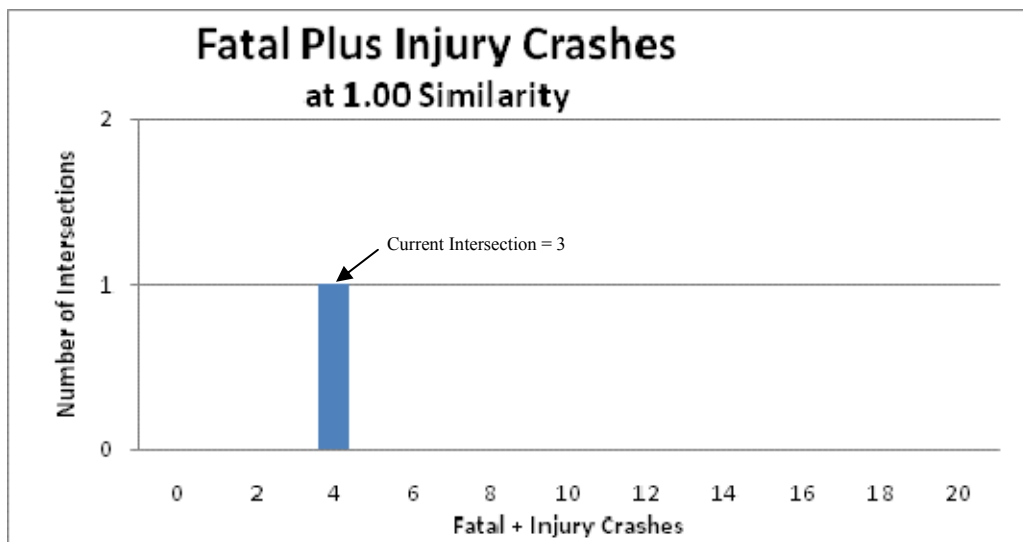
**Figure 29. Adjusted Fatal + Injury Crashes for Application 1 with 0.70 Similarity**



**Figure 30. Adjusted Fatal + Injury Crashes for Application 1 with 0.80 Similarity**



**Figure 31. Adjusted Fatal + Injury Crashes for Application 1 with 0.90 Similarity**



**Figure 32. Adjusted Fatal + Injury Crashes for Application 1 with 1.0 Similarity**

Using the tables and figures on the previous pages, one may estimate the safety effect of signalization. The similarity levels control the “likeness” of the comparison intersection to the candidate intersection. As the similarity level increases the number of intersections decreases. Comparison intersections are therefore better models of expected performance. However, as they are fewer in number, statistical reliability may be reduced.

Figures 12 through 18 illustrate that based on the experience of similar intersections and the inclusion of the candidate intersection’s attribute CRFs, should the intersection be signalized, one would expect between one and two crashes per MEV. This range is not unlike the crash rate of the candidate unsignalized intersection. Figures 19 through 25 indicate an expected rate of between 0.1 and 0.3 fatal and injury crashes per MEV. It could be concluded from figures 19 through 25 that the expected crash rate would most likely be in the lower half of the 0.1 to 0.3 fatal and injury crashes per MEV range. This is also not unlike the present rate.

Fatal and injury crashes are shown in figures 26 through 32. In this case, the intersection is presently experiencing a higher number of fatal and injury crashes than for comparable intersections. However, traffic volume at the site may be higher than the average of the comparison group. It would be appropriate at this point for the analyst to check volume levels further. Although the tool indicates the potential for reduction in total numbers of fatal and injury crashes, a site specific study would be warranted prior to implementing a signal. Further examination of the crash history would provide additional information to further support the decision of an engineer. This location in particular has geometric features that make it fairly unique, including the proximity of the aforementioned crest vertical curve and a bridge railing that limits sight distance on approach from the west, as these features are not currently accounted for in the database.

### 4.3. Application 2: Attribute Matching System for Safety Performance Prediction

The US 30 location was also used to illustrate the utility of the attribute matching capability of the case-based spreadsheet tool. To do this, selected intersection features were used to specify a group of comparison intersections that are closely matched on only one or a subset of attributes. This type of analysis not only allows for evaluation of potential safety effectiveness, but also the analysis of the specific effects of certain traffic, control, or geometric features. In practice, the attribute match system only considers attributes with completed values for the candidate intersection. Those that have no values are ignored in the comparison.

In this section, three graphical analyses are presented. First, only those comparison intersections that exactly match the existing intersection's major and minor volume classes are considered. This represents the use of the system to identify comparison sites where only the volume levels are known, and it is not yet known how the left turn treatment will be deployed if the intersection is signalized. See Table 7 for crash statistics and Figures 33 through 35 for crash rate and crash frequency histograms for the comparison group.

According to Table 7, 18 intersections match the major and minor volume levels of the candidate intersection. The comparison intersections experience an average crash values of 22.4 total crashes per MEV, 0.15 fatal plus injury crashes per MEV, and 2.33 fatal plus injury crashes per intersection. Examination of Figure 33 shows an expected total crash rate between 0.5 and 1.5 crashes per MEV for the comparison intersections. An expected fatal plus injury crash rate between 0.1 and 0.3 is graphically displayed in Figure 34. The comparison intersections have an expected number of fatal plus injury crashes between 2 and 4.

Total Number of Intersections	Crashes/Intersection	Fatal Crashes/Intersection
18.00	22.44	0.06
Injury Crashes/Intersection	Total Crash Rate (C/MEV)/Intersection	Fatal + Injury Crashes/Intersection
2.39	1.46	2.44
Fatal + Injury Crash Rate	Fatal Crash Rate (FC/HMEV)/Intersection	Injury Crash Rate (IC/MEV)/Intersection
0.15	0.29	0.14

Table 7. Average Crash Experience for Attribute Match Traffic Volumes Candidate Intersections

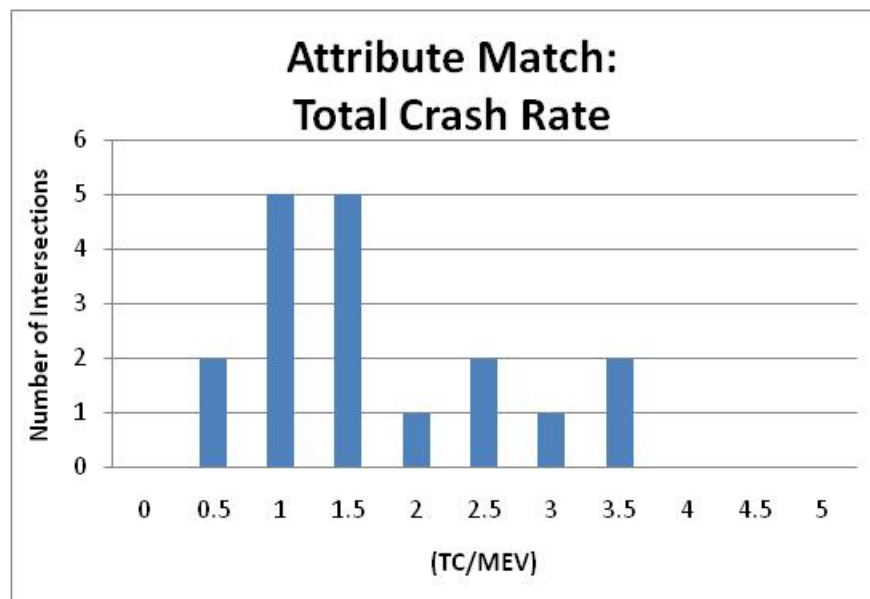
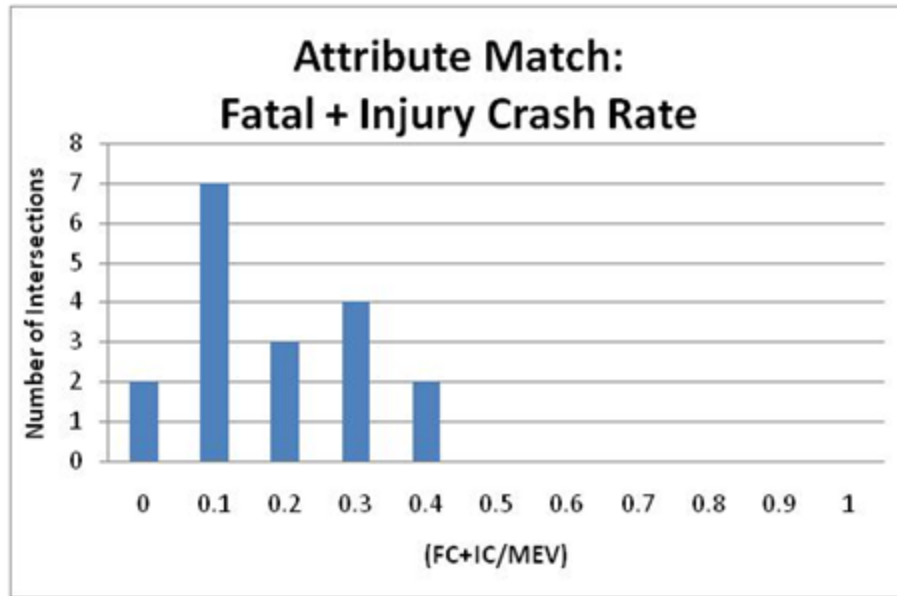
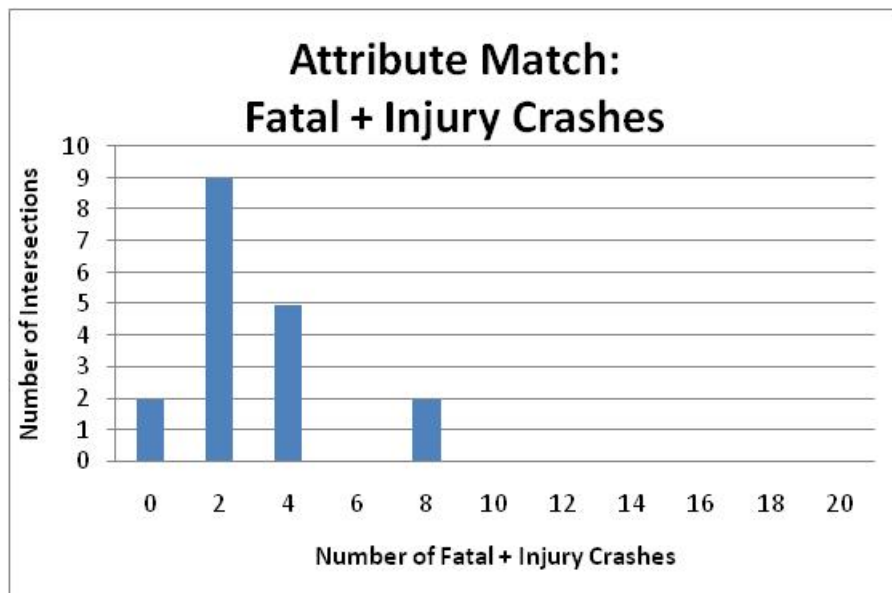


Figure 33. Total Crash Rate for Major and Minor Volume Attribute Match



**Figure 34. Fatal + Injury Crash Rate for Major and Minor Volume Attribute Match**



**Figure 35. Application 2: Fatal + Injury Crashes for Major and Minor Volume Attribute Match**

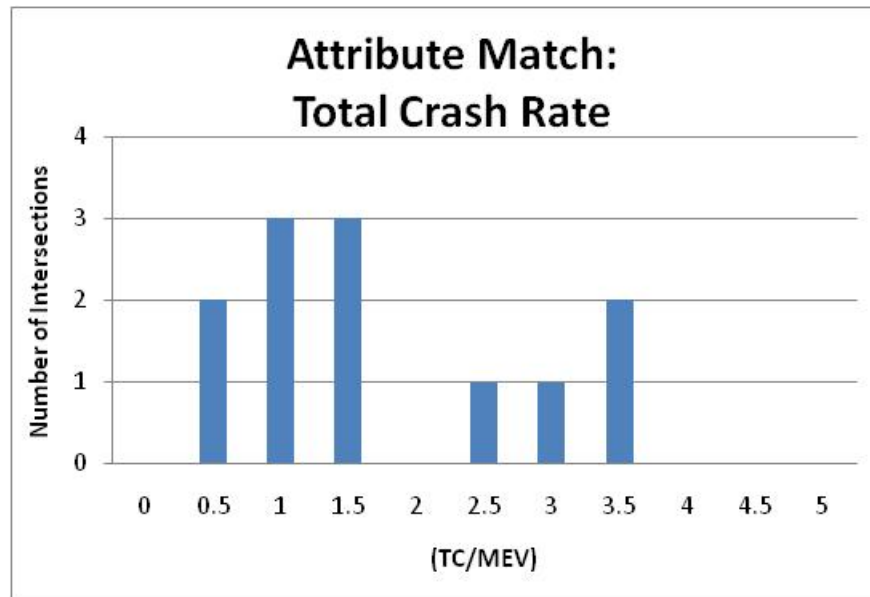


In the second analysis, this set is further refined to include only those intersections in similar volume classes with left-turn protected/permitted phasing (the most commonly provided left-turn treatment for high-speed signals in Iowa). See Table 8 for crash statistics and Figures 36 through 38 for crash rate and crash frequency histograms for the comparison groups.

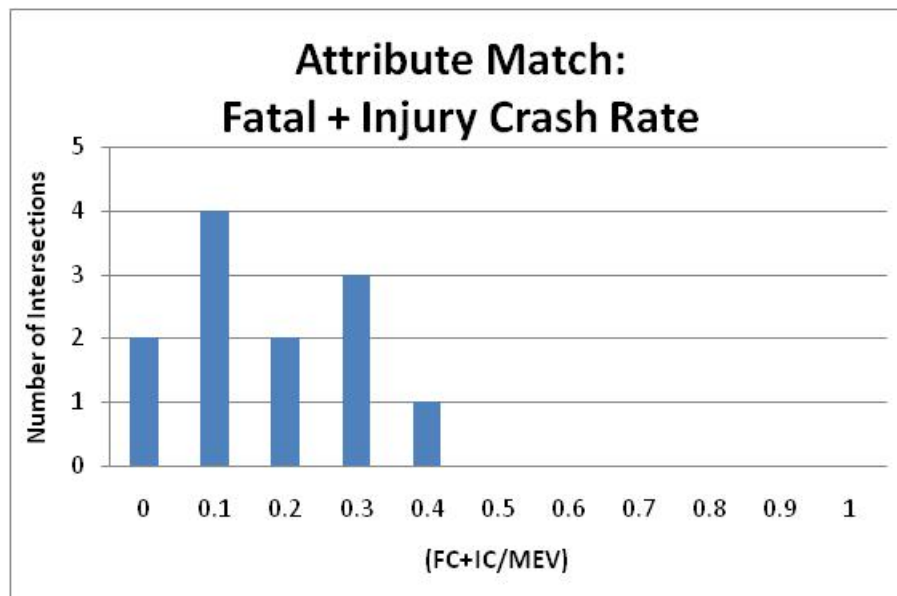
As shown in Table 8, the number of intersections included decreased from 18 in the previous analysis to 12 in this analysis. The reduction in the number of intersections should be considered when drawing conclusions from the table and figures. Figure 36 shows two clusters of total crash rates. The left cluster contains 8 of 12 intersections, and the right cluster contains 4 of 12 intersections. The histogram illustrates that a crash rate of 0.5 to 1.5 is expected, but the crash rate could be higher as shown by the right cluster. Figures 37 and 38 display results that have more defined groupings. A fatal plus injury crash rate between 0.1 and 0.3, and a fatal plus injury crash total between 2 and 4 are expected.

<b>Total Number of Intersections</b>	<b>Crashes/Intersection</b>	<b>Fatal Crashes/Intersection</b>
12.00	22.58	0.08
<b>Injury Crashes/Intersection</b>	<b>Total Crash Rate (C/MEV)/Intersection</b>	<b>Fatal + Injury Crashes/Intersection</b>
2.25	1.52	2.33
<b>Fatal + Injury Crash Rate</b>	<b>Fatal Crash Rate (FC/HMEV)/Intersection</b>	<b>Injury Crash Rate (IC/MEV)/Intersection</b>
0.15	0.43	0.14

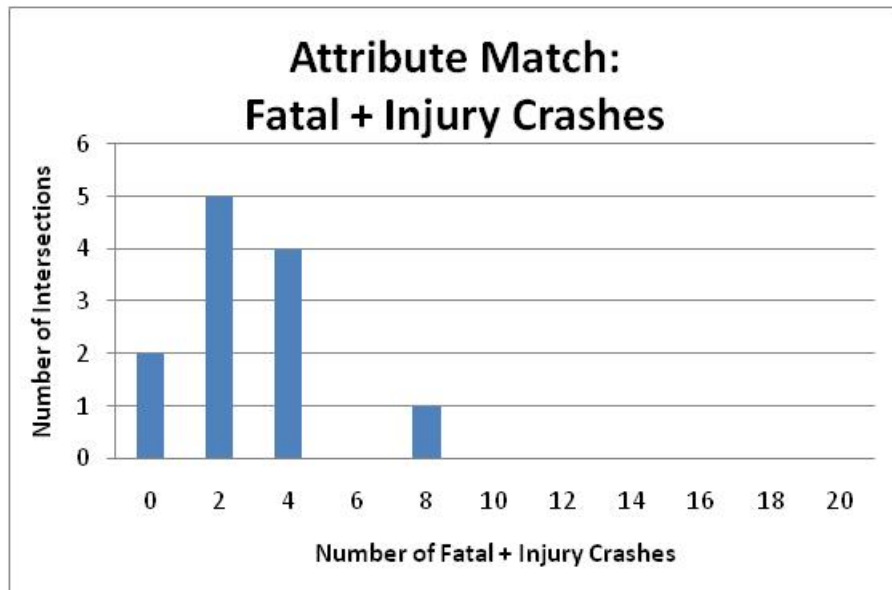
**Table 8. Average Crash Experience for Attribute Match Traffic Volumes with Permitted-Protected Phasing Candidate Intersections**



**Figure 36. Total Crash Rate for Volumes with Permitted-Protected Attribute Match**



**Figure 37. Fatal + Injury Crash Rate for Volumes with Permitted-Protected Attribute Match**



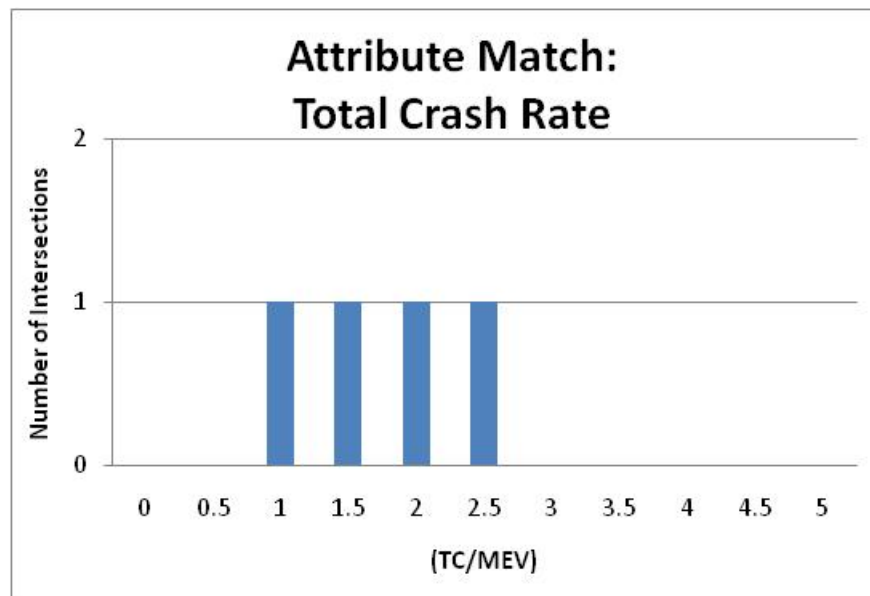
**Figure 38. Fatal + Injury Crashes for Volumes with Permitted-Protected Attribute Match**

In the third and last analysis of this section, the benefit of left-turn protected phasing is examined as only those intersections in similar volume classes with protected phasing are considered. See Table 9 for crash statistics and Figures 38 through 40 for crash rate and crash frequency histograms for the comparison group.

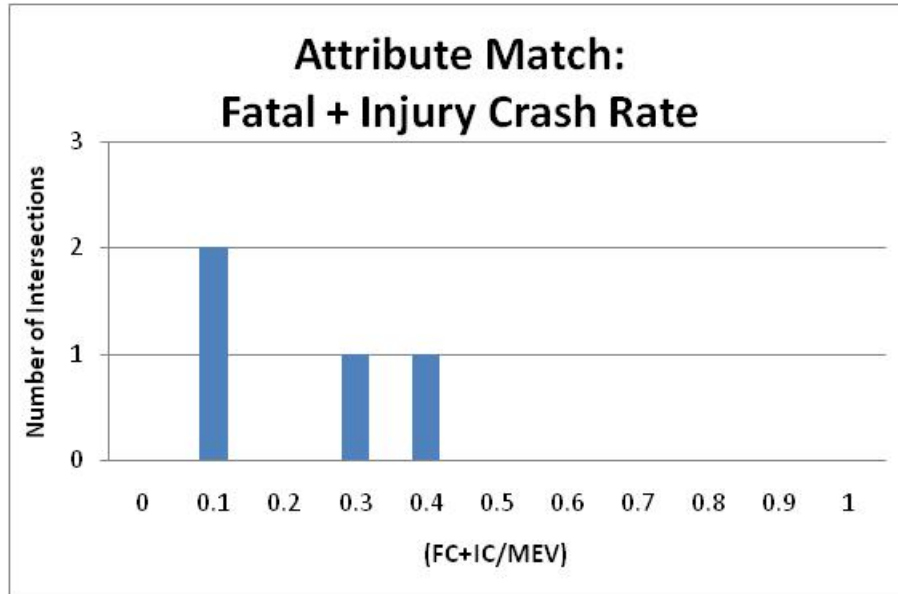
As shown in Table 9, only four intersections satisfied the matching requirements for this analysis. The Table provides the average crash values for these comparison intersections. Figures 38 through 40 provide only limited information because of the small number of intersections with rates ranging from 1.0 to 2.0 TC/MEV. However, these figures provide reliability information. While it may be concluded that the candidate intersection could experience between 1 and 2 total crashes per MEV, the statistical strength of any conclusions are weak due to the low number of intersections in the analysis.

Total Number of Intersections	Crashes/Intersection	Fatal Crashes/Intersection
4.00	26.75	0.00
Injury Crashes/Intersection	Total Crash Rate (C/MEV)/Intersection	Fatal + Injury Crashes/Intersection
3.25	1.49	3.25
Fatal + Injury Crash Rate	Fatal Crash Rate (FC/HMEV)/Intersection	Injury Crash Rate (IC/MEV)/Intersection
0.18	0.00	0.18

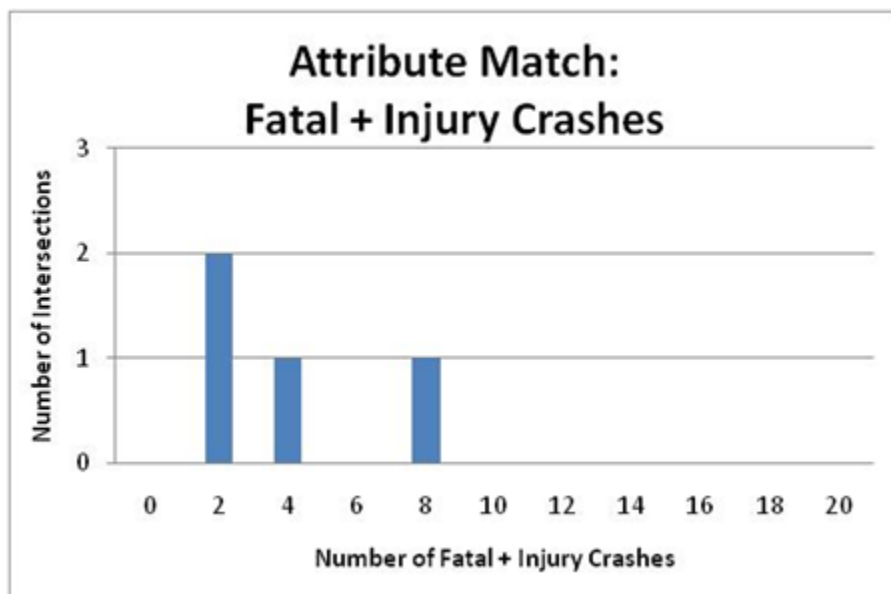
**Table 9. Average Crash Experience for Matching Volume and Protected Phasing**



**Figure 39. Total Crash Rate for Major and Minor Volume and Protected Phasing Attribute Match**



**Figure 40. Fatal and Injury Crash Rate for Volumes and Protected Attribute Match**

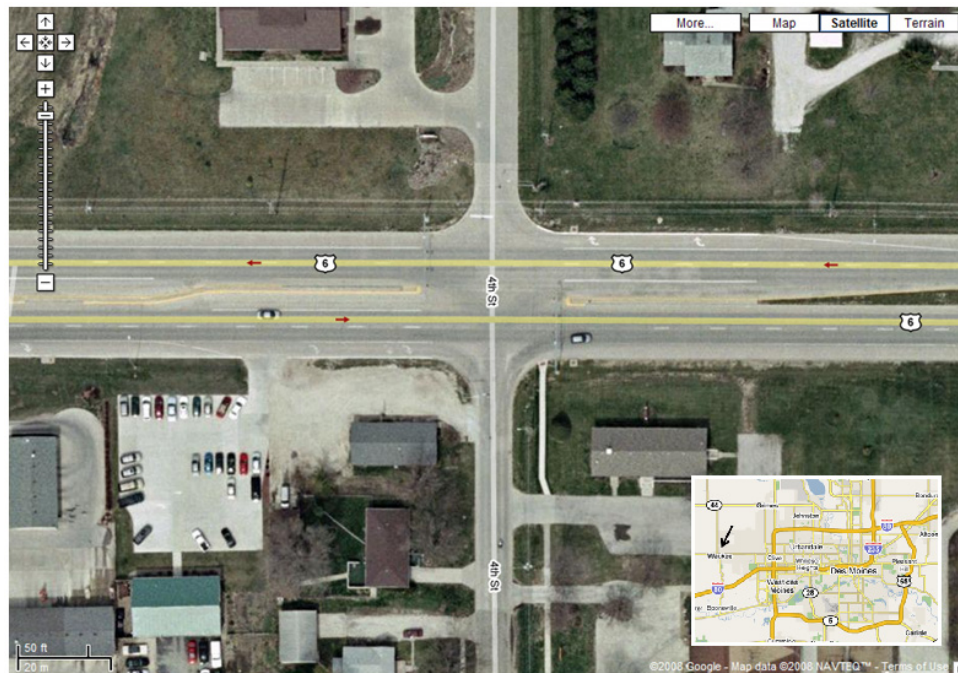


**Figure 41. Fatal and Injury Crashes for Volume and Protected Attribute Match**

As in the case of the similarity system, the user could continue to add attributes to the attribute match system, improving the similarity of the comparison and candidate sites, but significantly decreasing the number of comparison intersections. An advantage of the attribute matching system is that it allows the user to define, on the fly, the attributes he or she considers to be most important for comparison. Also as in the case of the similarity system however, the user is cautioned to conduct an engineering study of a site prior to recommending signalization or other significant modification.

#### 4.4. Application 3: Similarity System Safety Audit of an Existing Signalized Location

In this example, an existing signalized intersection is analyzed to determine its safety performance compared to other similar intersections. The location of the intersection chosen for this analysis is U.S. Highway 6 at 4<sup>th</sup> Street in Waukege, Iowa (See figure 42).



Source: Google Earth

**Figure 42. Location of Signalized Intersection for Applications 3 and 4.**

A similarity level of 0.75 was used for this analysis. The attributes and features of the present intersection are shown in table 10. These attributes are used to determine the comparison intersections that meet or exceed the 0.75 similarity level. Also shown in table 10 are the candidate intersection total crash rate, fatal plus injury crash rate, and number of fatal plus injury crashes from 2002 through 2006 for the candidate intersection. The actual average crash experience for the 0.75 similarity level comparison intersections are shown in table 11 and the adjusted crash experience in table 12. Figure 43 through 45 display the CRF adjusted comparison intersection histograms for total crash rate, fatal and injury crash rate, and frequency of fatal and injury crashes.

Present Attributes and Features		2002 through 2006 Crash Experience	
Major Roadway: Entering Vehicles	7,550	Total Crashes	8
Minor Roadway: Entering Vehicles	1,290	Fatal Crashes	0
Major Roadway: Horizontal Curvature	None	Injury Crashes	3
Major Roadway: Longitudinal Grade	1-5%	Fatal + Injury Crashes	3
Major Roadway: Speed Limit	45 MPH	Fatal Crash Rate (FC/MEV)	0.00
Number of Intersecting Roads	4	Fat. + Inj. Crash Rate (F+IC/MEV)	0.186
Major Roadway: Number of Through Lanes	2		
Major Roadway: Left-Turn Phasing	Prot-Per		
Major Roadway: Left-Turn Lane	Yes		
Major Roadway: Right-Turn Lane	Yes		
Intersection Lighting	Full		
Major Roadway: Median Type	Raised		
Major Roadway: Median Width	25		
Major Roadway: Advanced Warning	No		

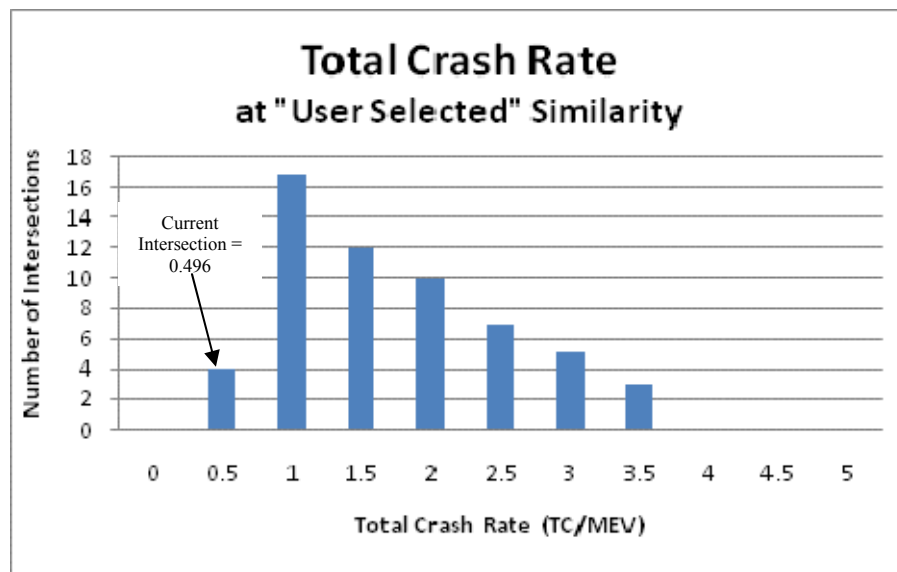
**Table 10. Present Intersection Attributes, Features, and Crash Experience**

	Total Number of Intersections	Crashes/Intersection	Fatal Crashes/Intersection
Selected	57.00	28.32	0.12
	Injury Crashes/Intersection	Total Crash Rate (C/MEV)/Intersection	Fatal + Injury Crashes/Intersection
Selected	3.30	1.50	3.42
	Fatal + Injury Crash Rate	Fatal Crash Rate (FC/HMEV)/Intersection	Injury Crash Rate (IC/MEV)/Intersection
Selected	0.18	0.62	0.17

**Table 11. Candidate Intersection's Actual Average Crash Experience**

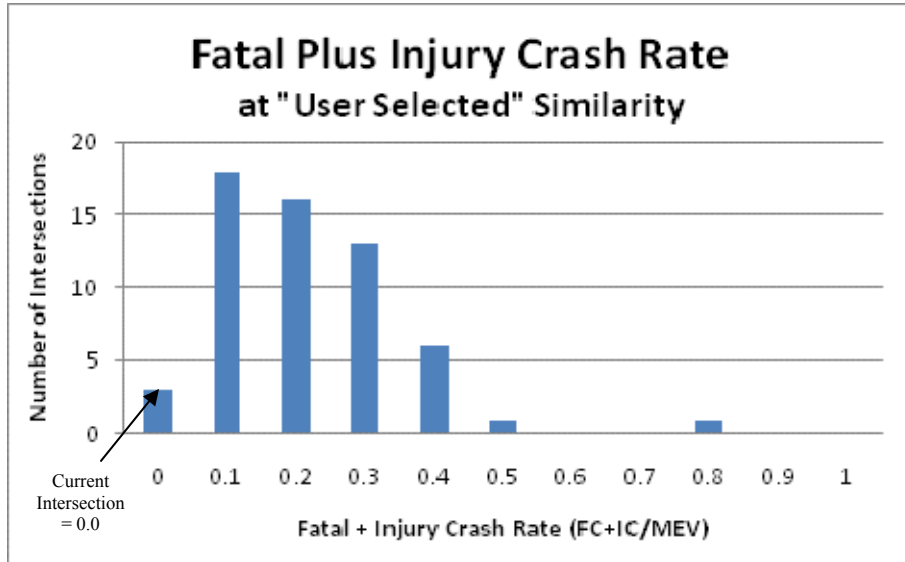
	Total Number of Intersections	Total Crash Rate	Fatal + Injury Crash Rate	Fatal + Injury Crash Frequency
Selected	18.00	0.93	0.16	2.80

**Table 12. Adjusted Comparison Intersection's Crash Experience**

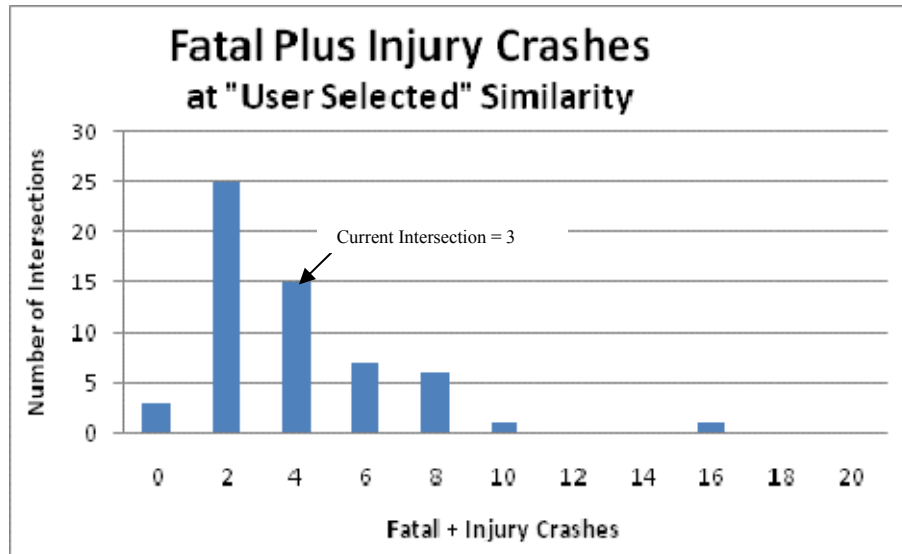


**Figure 43. Adjusted Comparison Intersection Total Crash Rate with 0.75 Similarity**





**Figure 44. Adjusted Candidate Intersection Fatal + Injury Crash Rate with 0.75 Similarity**



**Figure 45. Adjusted Candidate Intersection Fatal + Injury Crashes with 0.75 Similarity**

The actual average values for selected crash performance measures are shown in Table 11. The CRF adjusted crash experience is shown in Table 12. A comparison of the 2002 through 2006 crash experience at U.S. Highway 6 and 4<sup>th</sup> Street against the comparison intersections' actual and adjusted crash experience reveals information about the overall safety performance of the intersection. The comparison indicates that the intersection of U.S. Highway 6 and 4<sup>th</sup> Street performs at a similar level or is safer than the comparison sites. This conclusion is also supported by Figures 43 through 45.

Figures 43 through 45 provide the present intersection performance in addition to the candidate intersections' CRF adjusted crash performance for each crash measure. The present intersection's total crash rate of 0.496 total crashes per MEV is below the expected range of 1.0 to 2.0 as shown in Figure 43. The trend of safer performance continues in Figure 44 as the present intersection's fatal plus injury crash rate of 0.186 is on the lower end of the expected values between 0.1 and 0.4. Figure 45 illustrates that the intersection performs at a similar level to the CRF adjusted candidate intersections when examining fatal plus injury crashes. The present intersection experiences 3 fatal or injury crashes, and the expected value from the histogram is between 2 and 4.

#### **4.5. Application 4: Similarity System for Alternatives Analysis**

The case-based reasoning tool can also be used to conduct an alternative analysis for an intersection. The intersection of U.S. Highway 6 and 4<sup>th</sup> Street is used again in this analysis. A range of similarity levels was used (0.70 to 0.80) for this analysis. Table 13 provides the candidate and CRF adjusted comparison intersection and the above similarity level values for three intersection safety performance measures.

Present Attributes and Features			
Similarity	Total Crash Rate (C/MEV)	Fatal + Injury Crash Rate (F+IC/MEV)	Average Fatal + Injury Crashes
"Candidate"	0.496	0.186	3
0.80	1.07	0.12	2.04
0.75	1.55	0.16	3.22
0.70	1.50	0.16	3.22
Increased Major and Minor Volume			
Similarity	Total Crash Rate (C/MEV)	Fatal + Injury Crash Rate (F+IC/MEV)	Average Fatal + Injury Crashes
"Candidate"	0.496	0.186	3
0.80	1.65	0.19	5.18
0.75	1.55	0.20	5.91
0.70	1.33	0.20	5.31
Increase Speed Limit to 55 MPH			
Similarity	Total Crash Rate (C/MEV)	Fatal + Injury Crash Rate (F+IC/MEV)	Average Fatal + Injury Crashes
"Candidate"	0.496	0.186	3
0.80	0.82	0.09	1.58
0.75	1.21	0.13	2.54
0.70	1.50	0.13	2.54
Increased Volumes with 55 MPH Speed Limit			
Similarity	Total Crash Rate (C/MEV)	Fatal + Injury Crash Rate (F+IC/MEV)	Average Fatal + Injury Crashes
"Candidate"	0.496	0.186	3
0.80	1.27	0.15	4.12
0.75	1.22	0.16	4.75
0.70	1.33	0.16	4.75

**Table 13. Crash Measures at Three Similarity Levels for Application 4.**

Examination of the crash values for each of the similarity levels leads to several conclusions. When investigating the total crash rate, this intersection performs at a safer level than the comparison intersections. As shown in Table 13, the candidate intersection values for total crash rate is typically lower than the crash measures for the three similarity levels in each scenario. An increase in the major and minor volumes results in a higher fatal plus injury crash frequency for every similarity level, but the fatal plus injury crash rate is approximately the same at the similarity levels. The increased number of fatal plus injury crash rates can be explained by increased traffic exposure. The total crash rate ranges from a low of 1.33 at the 0.70 similarity level to a high of 1.65 for at the similarity level of 0.80.

Increasing the speed limit of a roadway typically results in an increased crash severity for most crashes. However, crash severity as shown in Table 13 (average number of fatal plus injury crashes) actually decreases as the similarity levels increase. This goes against the conventional thought that increased speed causes increased crash severities. This could be explained by the inclusion of fewer 55 mph intersections than other intersections. Examination of the crash values for the increased speed limit show an increase in the values from the 0.80 to 0.75 similarity levels. The number of intersections included also affects the crash values and the reliability of the data.

Increase in major and minor volumes as well as speed limit are portrayed in the last part of Table 13. As shown by the values in the table, the total crash rate and fatal plus injury crash frequency is more severe at all similarity levels as the traffic volume and speed limit is increased. This conclusion is consistent with conventional wisdom. Further examination of the similarity levels reveals that the most similar level has lower crash experience values, yet the candidate intersection has the highest fatal plus injury crash rate. While some of the candidate intersections included in the lower similarity levels might not match traffic volumes, speed limit, or both, they may be similar in other attributes to the candidate intersection.

#### **4.6. Summary**

This chapter has presented the results of four applications of the case-based reasoning high-speed signalization decision-support tool. The first application, expert system for safety performance, determined the effect of signalization at a two-way stop controlled intersection. The second application, attribute match for safety performance, tested the effect on intersection

safety of a few attributes. The third application, expert system for a safety audit, determined the safety performance of an existing intersection compared to the candidate intersections. Finally, the chapter presented an application of the tool for alternatives analysis, demonstrating the potential safety effects of changes in volume and speed limit as examples.

## **Chapter 5 Closure**

### **5.1. Summary**

Previous research on the safety effectiveness of high-speed expressway signals has produced limited results. Statistical analyses suffered from lack of data to support reliable models. Prior work using descriptive statistics was similarly inconclusive. Still, signals are deployed at least in part to address safety concerns at these locations.

When contemplating the installation of a signal, engineers may find it helpful to examine the past safety performance of signals at similar locations. Due to the large number of variables potentially affecting safety performance, sites which are candidates for signalization may be fairly unique, at least when compared to the limited number of locations available for comparison in a state such as Iowa. Even so, a database of some 135 locations was compiled for this research. In order to identify similar sites from the database, a case-based reasoning, spreadsheet based tool was developed in this study.

The spreadsheet tool provides two principal mechanisms for identification of similar sites for comparison: a similarity system based on expert opinions whereby intersection features are weighted by average ratings by field engineers to comprise an overall similarity score and an attribute matching tool for identifying similar intersections based on matching a subset of intersection attributes considered by the user to be important. The utility of the system is demonstrated in four applications which include example use of the two systems for estimating the safety performance of candidate intersection signalization as well as safety audit and alternatives analysis for existing signalized intersections.

## 5.2. Limitations

The chief limitations of this research are associated with the crash reduction factors (CRFs) and the number of intersections currently represented in the database. Currently, only Iowa high-speed expressway intersections are included covering speed limits of 45, 50, and 55 mph. Several Iowa intersections are not yet included because either they were signalized too recently (less than three years of after data available) or because it was beyond the resources of the present study to collect all feature data by field visit. Also, the CRFs used within the similarity system were not specific to a certain crash severity or traffic control type.

Another limitation is the availability of intersection attributes in the current database. While nearly comprehensive, at least two important features are missing: vertical curvature and sight distance limitations (for example, bridge railings near an intersection may impede sight distance).

Further, intersection features as represented in the database were collected by several different methods, each with different dates of collection. For example, aerial photos were generally available for the 2006 to 2007 time frame. GIMS data were for the 2006 end of year record. Field data were collected during the spring of 2008. As five years of crash data are provided (2002-2006), it is possible that some intersection features changed during this time frame.

Comparison values used in the case-based reasoning tool were determined from the *Federal Highway Administration Desktop Reference Guide for Crash Reduction Factors (CRFs)*. (FHWA, 2007) The CRF values were selected as the most appropriate values for determining the adjusted crash measures at this time. Limitations and inconsistent results of previous research represented in this reference will be reflected in the use of these data in the current work.

The system developed in this project is limited to the assessment of safety and does not provide the user with any indication of the operational performance of the candidate or comparison intersections. Further, while the crash data may include accidents involving pedestrians or bicycles, no intersection features related to these vulnerable users are included in the spreadsheet tool. Finally, the system does not provide any indication as to whether the candidate or comparison intersections meet MUTCD safety or other warrants for signalization, and these should always be checked.

### **5.3. Recommendations**

In addition to addressing the limitations identified in the previous section, several other recommendations are offered for future researchers or users of the case-based reasoning intersection signal evaluation tool.

First, the survey completed by the expert panel included a section for recommended additions to the attribute fields within the case-based reasoning tool. Several of the respondents indicated that the inclusion of an attribute field for isolated versus coordinated (or at least, proximate) signalized expressway intersections should be considered. Additional attribute or



feature field suggestions were regional location, weather, and the above mentioned sight distance and vertical curvature. The spreadsheet tool was designed to make the addition of attributes or features straightforward and simple, so that no programming knowledge is required beyond basic spreadsheet formulas.

Additionally, the methods used to determine the expected crash experience for the CRF adjusted data should be further investigated to provide the most accurate CRF available. Further study of the research and analysis methods for determining the CRFs in FHWA document may provide more appropriate CRFs to be applied to the crash data. With the inclusion of additional analysis of the CRFs it is recommended to further revisit and refine the CRFs. A similar recommendation can be made regarding the use of qualitative (fuzzy) terms used to describe some features such as horizontal curvature, as these may be quantified in future applications.

A useful enhancement to the system would be the inclusion of a list of recommended countermeasures tailored to the crash experience of the candidate intersection. The system could then be modified to identify comparison sites where these countermeasures have been implemented. Another useful enhancement would be the inclusion of data to quantify the before and after performance of similar intersections that have been signalized. These data are available in previous studies of the Iowa intersections. Also, an interactive map that displays the intersection locations statewide, hyperlinked to data and imagery for each comparison site would be an interesting and useful addition.

Finally, the case-based reasoning tool should be updated as is possible with the latest crash and intersection feature data as they become available. Older data should be retained, but somehow time stamped to indicate collection date. It is important to include new crash data that are relevant for the same time period as feature data, and that existing information in the database be checked for this, and replaced as necessary.

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## **Appendix A**

### **Expressway Selection Queries**

`([Direction2]="S")and([Limitmph] = xx)and([Gradesigna] >=1)and([Accessentl] >=2)`

Direction2 only exists if the roadway is divided and has lanes traveling in both directions

Limitmph is the speed limit for each segment of the GIMS data

Gradesigna is the number of signals located on the segment of the GIMS data

Accessentl is the type and number of points at which traffic is allowed to enter or exit a roadway

2 = expressway

3 = planned access with through traffic given primary consideration

4 = planned access with through traffic and land services traffic given equal consideration

### **IaDOT Crash Data**

All relevant tables were incorporated into the crash data used within this project. The tables included are as follows:

Crash Level: zcta, zenv, zltp, zsev, and zrda

Driver/Vehicle Level: zctb, zdrv, zrdb, and zveh

Injury Level: zinj

The years selected were 2002 through 2006.

## Appendix B

	Traffic Volume	Horizontal Curvature	Longitudinal Grade	Speed Limit	Number of Intersecting Roadways	Number of Through Lanes	Intersection Skew	Presence of Left-Turn Lane	Presence of Right-Turn Lane	Intersection Lighting	Advanced Warning Sign	Median Type	Median Width	Left-Turn Phasing	Rural vs. Urban
Ranking (1 to 10)															

**Instructions:**

Please rank each attribute based on the significance of the attribute in determining similarity to other intersections. Please rank the attributes using numerical values from high importance (10) to low importance (1)

**Explanation of Terms:**

**Traffic Volume:** The average daily traffic (ADT) for each leg of the intersection.

**Horizontal Curvature:** A degree of curvature before the intersection that affects intersection recognition.

**Longitudinal Grade:** The grade of the roadway in the direction of travel.

**Speed Limit:** The posted speed of each intersection leg.

**Number of Intersecting Roadways:** The number of legs at the intersection location.

**Number of Through Lanes:** The number of lanes that are not considered "turn" lanes.

**Intersection Skew:** The angle that the roadways intersect.

**Presence of Left-Turn Lane:** Any type of left-turn lane.

**Presence of Right-Turn Lane:** Any type of right-turn lane.

**Intersection Lighting:** The lighting of the intersection during darkness.

**Advanced Warning Sign:** The advanced warning of an approaching intersection.

**Median Type:** Grassy, Paved, or Other

**Median Width:** Various widths in feet.

**Left-Turn Phasing:** Permitted, Protected, or Permitted-Protected

**Rural vs. Urban:** The location of the intersection

Thank you for participating in this survey. Your cooperation is appreciated.